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Davis, CA

FSCBG Modeling Comparisons With The Heather Seed Orchard Deposition Data

FPM 90-5 (2)
May 1990

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FSCBG MODELING COMPARISONS WITH THE HEATHER SEED ORCHARD DEPOSITION DATA

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TABLE OF CONTENTS

Section		Page
	TABLE OF CONTENTS	i
	ABSTRACT	ii
	ACKNOWLEDGMENTS	iii
	EXECUTIVE SUMMARY	iv
1.	INTRODUCTION	1-1
2.	INPUT PARAMETRIC ANALYSIS	2-1
3.	RESULTS	3-1
4.	CONCLUSIONS	4-1
5.	REFERENCES	5-1
	APPENDIX	A-1

ABSTRACT

In the summer of 1989 the Forest Pest Management Staff (USDA Forest Service) cooperated with Willamette National Forest, Oakridge, OR, to monitor pesticide spraying of the Heather Seed Orchard. In this report, card and string line data are compared with canopy penetration and deposition predictions from FSCBG, the Forest Service computer model that predicts transport and behavior of pesticide sprays released from aircraft. Predictions confirm the utility of the computer model to simulate deposition in a Douglas-fir canopy, predicting canopy penetration and ground deposition to within an average of 8.3 percent of data for all data collected. These results substantiate the process of accessing a computer model to set spray parameters for future missions and establishing nominal procedures for spraying these canopies safely and effectively.

ACKNOWLEDGMENTS

Data collection and project completion could not have been accomplished at the Heather Seed Orchard without the coordinated efforts of the following USDA Forest Service personnel:

J. R. Dewitz, District Silviculturist at the Oakridge Ranger District

R. E. Sandquist, Reforestation Insects Entomologist

K. P. Bentson, Research Chemist

R. B. Ekblad, Mechanical Engineer

J. W. Barry, Program Manager.

(5) Atmospheric data collected at the Heather site, with a portable meteorological tower, were invaluable for quantifying the wind speed, wind direction, ambient temperature and relative humidity during the spray applications. This data acquisition tower and instrumentation should be made available for future studies of this kind.

(6) Pretest deposition predictions using FSCBG gave coverage levels consistent with observed data collected during the spray applications, even though the ambient temperature and relative humidity ranges considered were beyond the actual atmospheric conditions encountered. Future spray applications should utilize FSCBG to plan the spray mission parameters and provide predictions beyond the range of ambient temperature and relative humidity anticipated during spraying.

1. INTRODUCTION

The USDA Forest Service in cooperation with the U. S. Army has developed the Forest Service Cramer-Barry-Grim (FSCBG) aerial spray model (Curbishley and Skyler, Ref. 1) and the Agricultural Dispersal (AGDISP) model (Teske, Ref. 2). These models predict the transport and behavior of pesticide sprays released from aircraft. The current version of FSCBG, designated FSCBG (PC) for the personal computer, contains the aircraft complex wake model developed for AGDISP. The FSCBG model has undergone several major enhancements over the past ten years, including features to accommodate the following:

(1) Droplet evaporation;

(2) Forest canopy droplet penetration; and

(3) Complexities of the aircraft wake as it influences spray behavior.

In 1989 FSCBG activity included:

(1) Improving its graphics capability in the personal computer environment;

(2) Correcting coding errors and improving code performance;

(3) Improving the readability and content of the user manual; and

(4) Responding to questions and concerns raised by code users.

A significant area that has not kept pace with the coding improvements is on-going comparison of predictions with field data. To date FSCBG predictions have been compared with the following data:

(1) Dugway drift study over desert (Boyle, et al., Ref. 3);

(2) Withlacoochee (Southeastern) seed orchard (Rafferty, et al., Ref. 4); and

(3) Red Bluff (California) forested area (Rafferty and Bowers, Ref. 5).

Comparisons with data require the field researcher to collect and provide all of the inputs needed by FSCBG. In particular, the canopy penetration model requires:

Canopy height

Stand density (stems per acre)

Penetration probability

Vegetative element size

Tree envelope

These parameters are either obtained from inspecting the trees to be sprayed, or determined by comparing code predictions with field data.

An opportunity to evaluate the aerial application of insecticides in western seed orchards occurred when the Oakridge Ranger District of the Willamette National Forest requested assistance in improving the effectiveness of insecticide treatments by using aerial spray application to control seed and cone insects of Douglas-fir. Consistent with this request, an FSCBG simulation effort was undertaken with a two-fold purpose:

(1) Investigate canopy penetration and deposition of insecticide sprays; and

(2) Evaluate the drift of insecticides off-site.

This information would then be used to further validate the FSCBG computer simulation model for spray behavior in Douglas-fir seed orchards. The overall objective of this evaluation, of course, was to determine the effectiveness of an aerial spray application regime to protect Douglas-fir cones and seed from harmful insects. The use of FSCBG to simulate spray behavior would quantify spray mission parameters specific to the site in question.

Coordination for the spray project came from J. R. Dewitz, District Silviculturist at the Oakridge Ranger District.

The spray project consisted of three applications to the trees (Sandquist, Ref. 6). The first application took place on April 27, 1989; the second, on June 7 and the third, on July 6. The April application sprayed Guthion 35W, while the June and July applications sprayed Asana XL. Rhodamine WT dye was added to the tank mix to aid in assessment of spray deposit on Kromekote cards, drift sampling strings and foliage. Ground and canopy deposition data, collected by Bentson (Ref. 7), was used to compare with FSCBG predictions.

The three applications were highly successful in reducing seed cone losses resulting from insects (Sandquist, Ref. 8). Empirically, Sandquist suggests that untreated cones produced only twenty percent usable seed compared to a potential of ninety percent when treatment is successful (R. E. Sandquist, private communication).

The April test data (with Guthion 35W) suffered from two shortcomings:

(1) A portable meteorological tower was not in place to record ambient atmospheric conditions during the application; and

(2) The aircraft tank wash was inadvertently deposited on a portion of the orchard, polluting the deposition cards with an unknown additional application.

Consequently, this report will concentrate on the June and July spray applications (with Asana XL) for which sufficient meteorological data were obtained to complete the necessary inputs to FSCBG. Herein, FSCBG predictions are compared with deposit card and string chemical assay data collected during the spray applications, reduced by Bentson (Ref. 9) and transmitted to Continuum Dynamics, Inc., and reported by Bentson, et al. (Ref. 10).

This report follows the work plan previously submitted (Teske, Ref. 11) and the pretest predictions made with FSCBG after the April spray application (Teske, Ref. 12).

2. INPUT PARAMETRIC ANALYSIS

The Heather Seed Orchard site is shown schematically in Figure 2-1. The site is divided into two sections, a dense tree spacing section and a sparse tree spacing section where considerable thinning has occurred over the years. One objective of the present study is to compare predictions with data from both tree stand areas, since the only apparent parameter change should be in stems per acre.

Table 2-1 summarizes the nominal input parameters to FSCBG. Several of these parameters were obtained from visits to the orchard in May, June and July. Others were obtained from R. E. Sandquist (private communication).

CANOPY CHARACTERISTICS

Canopy height was inferred by transit measurements of five representative Douglas-fir trees in the sparse tree stand area. Slides taken of these trees were then projected onto a surface, and the plant envelope (Table 2-2) was determined. An average canopy height of 15 meters was obtained by this technique. Stems per acre, penetration probability and element size were estimated at the orchard.

Independently, Bentson, et al. (Ref. 10) determined average tree heights (using twenty sample trees) of 16.4 m (in the sparse section) and 19.6 m (in the dense section). Since the Douglas-fir trees are conical in shape, it was felt that variations in height would not be critical as long as the width was determined accurately. Subsequent to these measurements, a comparison was made for average ground deposition (with the June application conditions) in the sparse and dense tree stand areas (Figure 2-2). The profile shape given in Table 2-2 was scaled to these other heights. The deposition results indicate that average ground deposition is, however, a strong function of canopy height. For the present study an average height of 15 meters will be used.

Stand densities (stems per acre) were computed by walking the orchard site, and confirmed by the average distances to nearest neighbors (K. P. Bentson, private communication). The dense tree stand area may in fact have a higher stand density than assumed here; however, subsequent calculations (Figure 2-3, June application) demonstrate that above 120 stems per acre, the effect of the parameter is seen to diminish. The trend is correct here: as the number of trees increase, less material should transverse the canopy and deposit on receptors placed on the ground.

Stand density is nonetheless an important parameter in the representation of a forest canopy. The sparse tree stand area has an estimated density of 25 stems/acre, while the dense tree stand area has an estimated density of 120 stems/acre. The ground deposition cards nearest the tree trunks found ground deposition approaching zero (Bentson, Ref. 9).

Penetration probability was estimated visually from the trees in the sparse tree stand area to be 0.38. The intention of the present study is to quantify this parameter in the sparse and dense tree stand areas for Douglas-fir. Subsequent calculations (Figure 2-4, June application) demonstrate the influence of penetration probability on deposition. The trend is again correct here: as penetration probability decreases, less material should traverse the canopy and deposit on receptors placed on the ground.

Vegetative element size is that portion of the tree that acts as its capture surface. Douglas-fir branch tips tend to act as a unit when responding to local wind effects, and may

in fact act as a single unit when capturing deposition. A nominal length of three centimeters is assumed here. Subsequent calculations with the June application (Figure 2-5) show that average ground deposition does not change even when the vegetative element size is increased to 12 centimeters. Average ground deposition is independent of this parameter in this application.

AIRCRAFT CHARACTERISTICS

The aircraft characteristics were obtained from the applicator, observations during the applications (J. R. Dewitz, private communication) and checking with tabulated aircraft characteristics (Hardy, Ref. 13) for the Bell 47G3B2 helicopter (schematic shown in Figure 2-6). The aircraft weight was taken as one-half the useful payload weight.

The aircraft speed was assumed to be 40 mph (nominal value specified to the applicator). Subsequent calculations (Figure 2-7) show that average ground deposition does not change in this application as the aircraft flight speed is changed. Aircraft flight speed, however, is critical for defining the strength of the rotor tip vortices that carry spray material from the nozzles to the top of and into the canopy.

Spray release height is a more important parameter, as increased spray release height increases downwind drift of released material in a crosswind situation. The value assumed here is the nominal value of 20 feet specified to the applicator. Subsequent calculations (Figure 2-8) show a strong deposition effect due to release height, and suggest that a slightly higher spray release height (25 to 30 feet) would have improved the average ground deposition. Bentson, et al. (Ref. 10) suggest that the aircraft may have been flying as high as 15 m above the canopy. The consequences of this parameter will be explored in Section 3 of this report.

SPRAY CHARACTERISTICS

The June and July applications sprayed Asana XL. The spray volatile fraction was inferred from the known amount of spray material (0.29 gallons of Asana XL) added to the known amount of water (per 5 gallons of water). Rhodamine WT dye was added to the tank mix to mark deposition levels on samplers through the canopy height, spray deposit cards on the ground, and cotton string stretched across the boundaries of the spray area. The spray drop size distribution was obtained from Yates, et al. (Ref. 14), and is reproduced here in Table 2-3.

The spray boom contained 34 nozzles, symmetrically located along the boom. Since FSCBG is limited to a total of 20 nozzles in a simulation, an effective nozzle distribution was constructed by averaging the spanwise position of adjacent nozzles and placing a nozzle along the aircraft centerline. Table 2-4 tabulates the actual and modified nozzle positions. For this prediction it is assumed that the aircraft made eight passes over the site, depositing material at the rate of 5 gal/acre with a swath width of 18.3 meters. In actuality the aircraft flew each swath twice (sixteen passes) at the rate of 2.5 gal/acre.

Swath length was assumed to be 183 meters. In the actual applications some attempt was made to spray the trapazoidal shape shown in Figure 2-1, but that enhancement is not shown here.

Swath width was assumed at 18.3 meters, and was subsequently verified by the Complex Wake (AGDISP) deposition for a spray release height of 6.1 meters above the canopy (Figure 2-9).

METEOROLOGICAL CHARACTERISTICS

Wind speed, wind direction, ambient temperature and relative humidity were determined at the orchard by aid of the EMCOT Weather Station (Ekblad, et al., Ref. 15). FSCBG inputs cannot have flight lines parallel to the ambient wind direction because of a mathematical singularity. For this reason the ambient wind was rotated five degrees off the flight lines. This assumption is permissible because of the low ambient wind speeds observed during the applications.

Atmospheric conditions for the June application are shown in Figure A-1 in the Appendix for horizontal wind speed, wind direction, vertical wind speed and ambient temperature. Test time was 7:12 AM (PDT) on June 7, 1989 (7.20 hours). The minimum wind speed that can be recorded by the horizontal sensor is just below 0.5 meters per second. The quiet, cool downslope drainage winds vary dramatically once the sun crests the local hills and enters the orchard. Spraying occurred just before this happened. The relative humidity was measured with a sling psychrometer to be 85 percent (R. B. Ekblad, private communication).

Corresponding plots for the July application are shown in Figure A-2 in the Appendix. Test time was 6:39 AM (PDT) on July 6, 1989 (6.65 hours). The relative humidity sensor was saturated, but an estimate suggested a relative humidity of 95 percent during the application.

Subsequent sensitivity studies of relative humidity and ambient temperature (June application) are shown in Figures 2-10 and 2-11 respectively. Both trends are consistent here. As relative humidity increases, evaporative effects decrease, and more material travels through the canopy to the ground. Conversely, as ambient temperature increases, evaporative effects increase, and less material travels through the canopy to the ground.

Relative humidity and ambient temperature are important quantities, as they control the amount of volatile evaporation. The portable meteorological tower established their levels in the June and July applications. The EMCOT Weather Station (or comparable system) should be used to quantify meteorological parameters during future spray applications.

PRELIMINARY CALCULATIONS

Pretest predictions for the June and July applications assumed nominal meteorological conditions significantly different from those observed during the actual spraying. At the suggestion of J. R. Dewitz (private communication), and based on records at Oakridge, the following conditions were assumed:

	June	July
Ambient Temperature (deg C)	10.0	14.2
Relative Humidity (percent)	35.0	20.0

Results for these conditions are shown in the Appendix in Figures A-3 and A-4 at the top of the canopy, and Figures A-5 and A-6 at the ground. The predictions demonstrate the significant effect of relative humidity on deposition. The contours at the top of the canopy (Figures A-3 and A-4) are quite similar, while the contours at the ground (Figures A-5 and A-6) are quite different. Maximum predicted ground deposition in the June application was 0.167 gm/m^2, and in July, 0.093 gm/m^2. As may be seen by these plots, the predicted deposition is nearly independent of position along the flight lines in the interior of the spray area.

The actual application conditions are examined in the next section of this report.

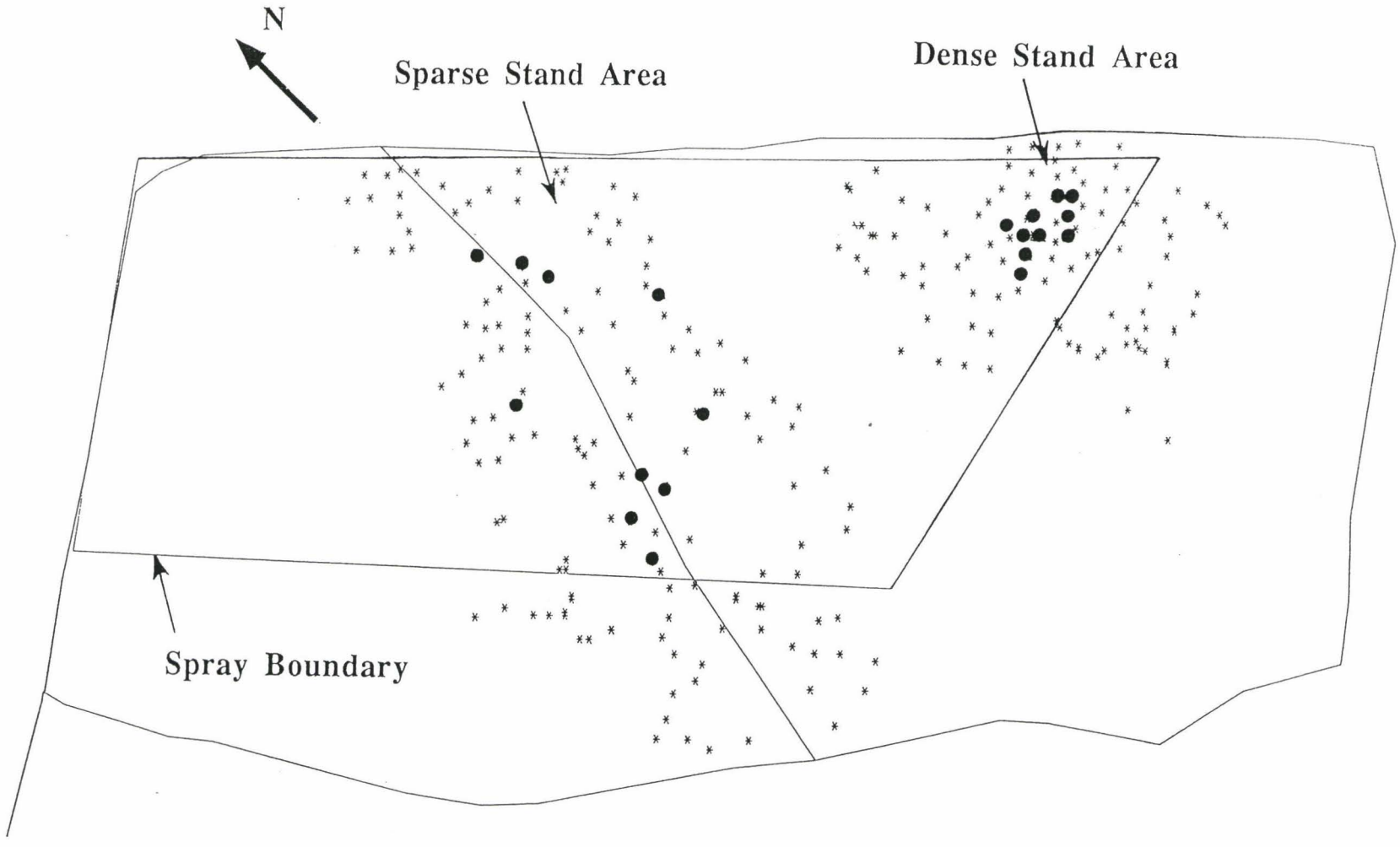

Figure 2-1: Heather Seed Orchard (1989) schematic (1 cm = 27 m). Douglas-fir trees in the sparse and dense tree stand areas are shown as asterisks (*). Sample trees are denoted by solid circles (●). The nominal spray area is indicated by the trapezoidal shape as shown.

Table 2-1

Nominal Heather Seed Orchard Inputs to FSCBG

Canopy height	15.0 m
Stand density (stems per acre)	25.0 (sparse stand area)
	120.0 (dense stand area)
Penetration probability	0.38
Vegetative element size	3.0 cm
Aircraft type	Bell 47G3B2
Aircraft weight	10,800 Newtons (2,420 lbf)
Rotor diameter	11.4 m
Blade rotation rate	350 rpm
Aircraft speed	17.9 m/sec (40 mph)
Spray release height (above canopy)	6.1 m (20 ft)
Spray specific gravity (tank mix)	0.997 (Asana XL)
Spray volatile fraction	0.942 (Asana XL)
Swath width	18.3 m (60 ft)
Swath length	183.0 m
Application rate	2.5 gal/acre (double passes)
Nozzle type	D4-45 at 90 deg
Ambient wind speed	1.0 m/sec
Wind direction	Nearly parallel to flight lines
Ambient temperature	4.4 deg C (June)
	7.6 deg C (July)
Relative humidity	85.0 percent (June)
	95.0 percent (July)

Table 2-2

Nominal Heather Seed Orchard Plant Envelope

Average of five representative trees

Height in Canopy (m)	Minimum Diameter (m)	Mean Diameter (m)	Maximum Diameter (m)
15.0	0.0	0.0	0.0
13.5	0.08	1.37	3.74
12.0	1.52	2.87	4.79
10.5	2.17	3.12	3.67
9.0	3.05	4.41	5.61
7.5	3.85	5.12	5.96
6.0	4.57	5.76	6.88
4.5	4.65	6.01	6.95
3.0	5.30	5.85	6.41
1.5	4.19	4.74	5.47

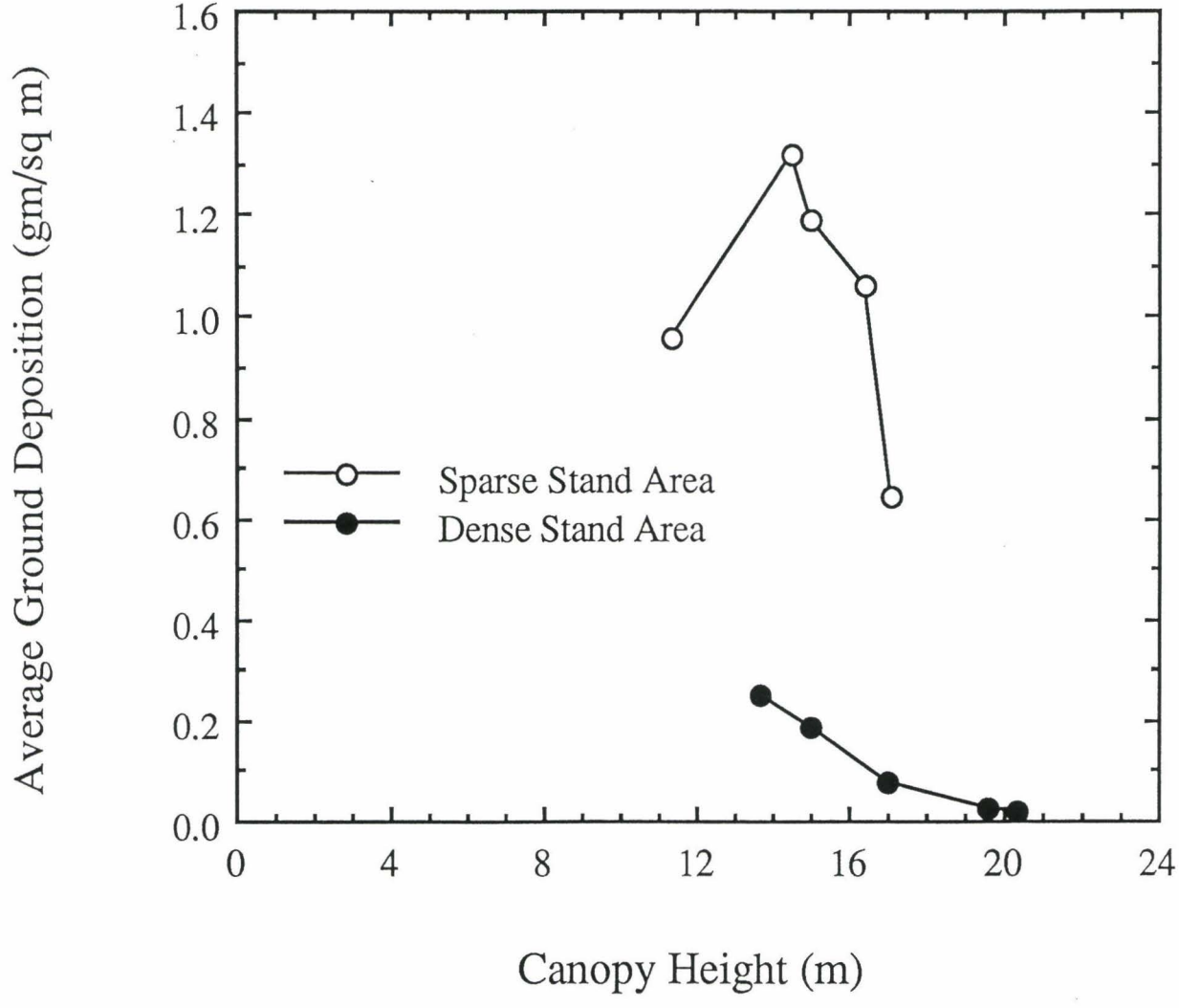

Figure 2-2: Average predicted ground deposition as a function of Canopy Height for the Heather Seed Orchard canopy (June application). The open circles indicate deposition in the sparse tree stand area, and the solid circles indicate deposition in the dense tree stand area. The largest and smallest values of Canopy Height bracket the tree heights determined by K. P. Bentson (private communication). The nominal canopy height is 15 meters.

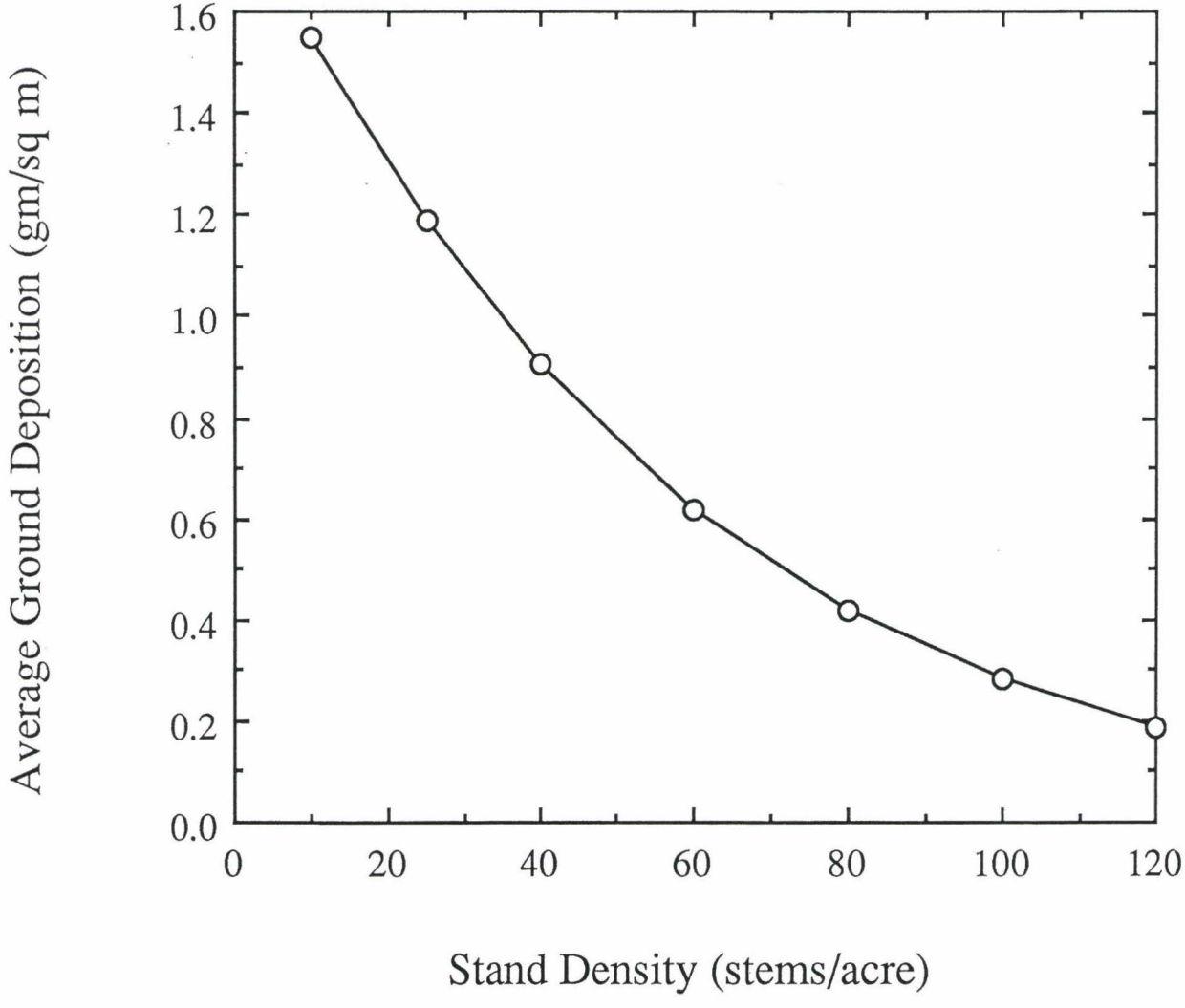

Figure 2-3: Average predicted ground deposition as a function of Stand Density for the Heather Seed Orchard canopy (June application). The nominal stand density is 25 stems/acre for the sparse tree stand area, and 120 stems/acre for the dense tree stand area.

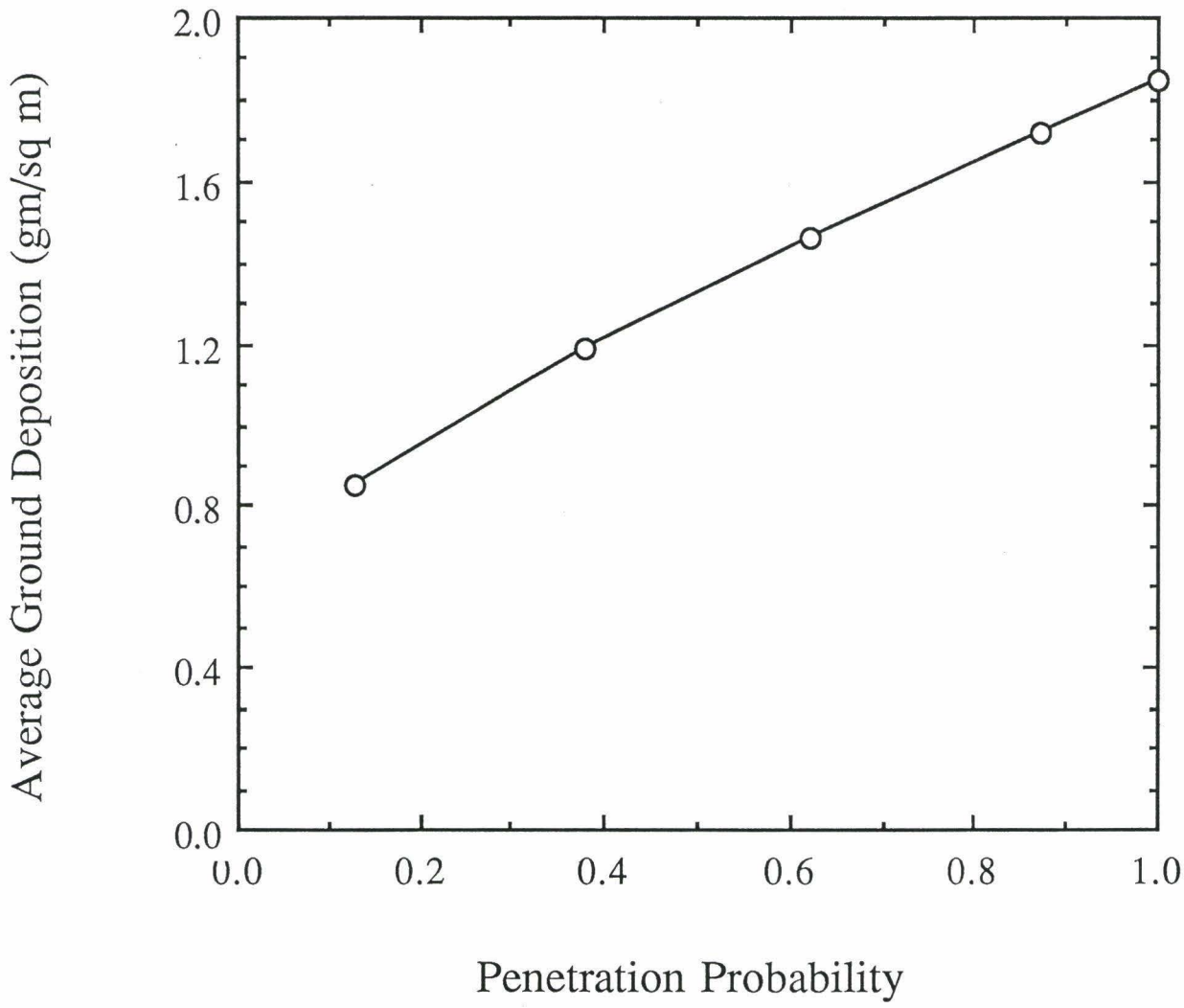

Figure 2-4: Average predicted ground deposition as a function of Penetration Probability for the Heather Seed Orchard canopy (June application). The nominal penetration probability is 0.38.

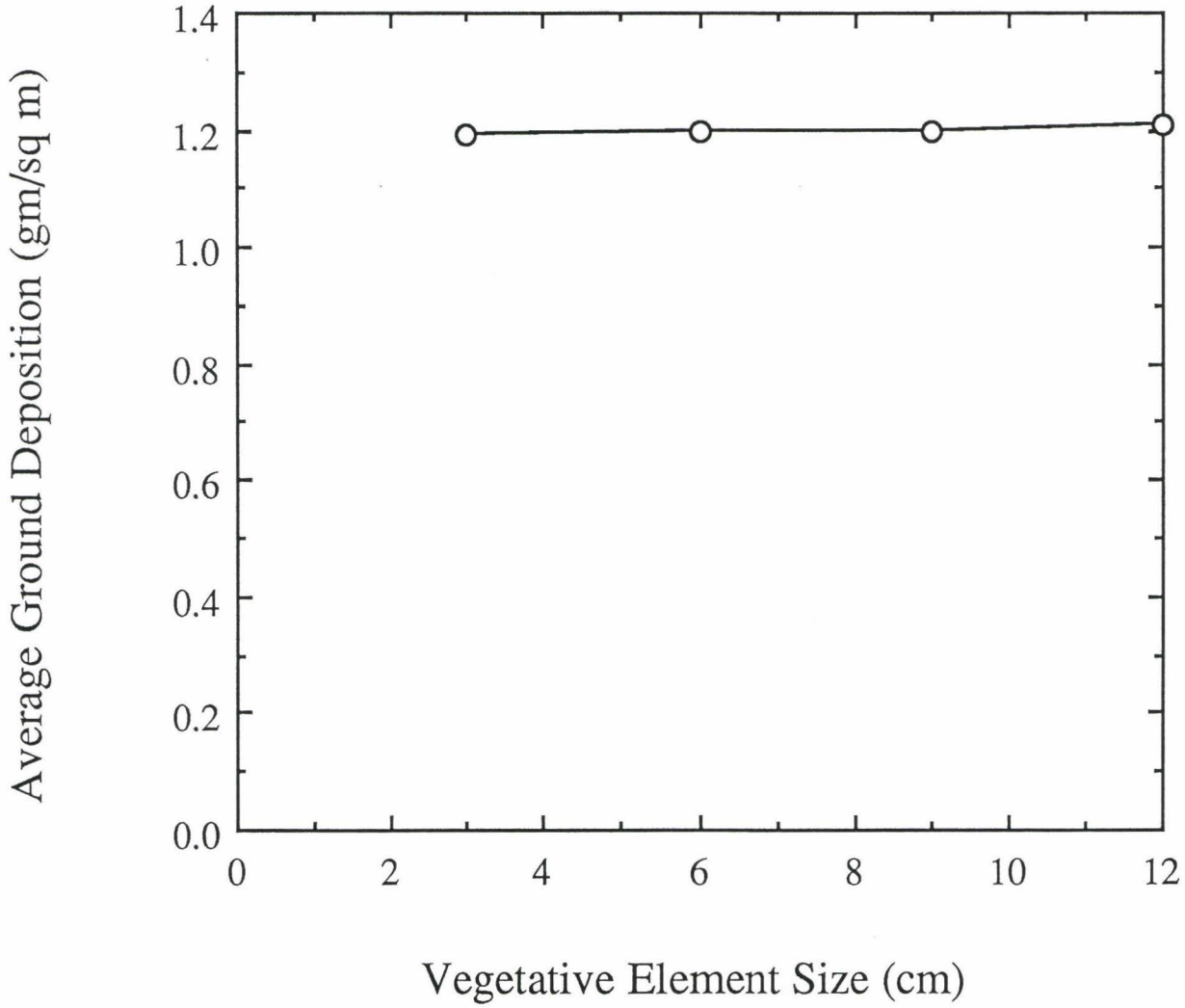

Figure 2-5: Average predicted ground deposition as a function of Vegetative Element Size for the Heather Seed Orchard canopy (June application). The nominal element size is 3 cm.

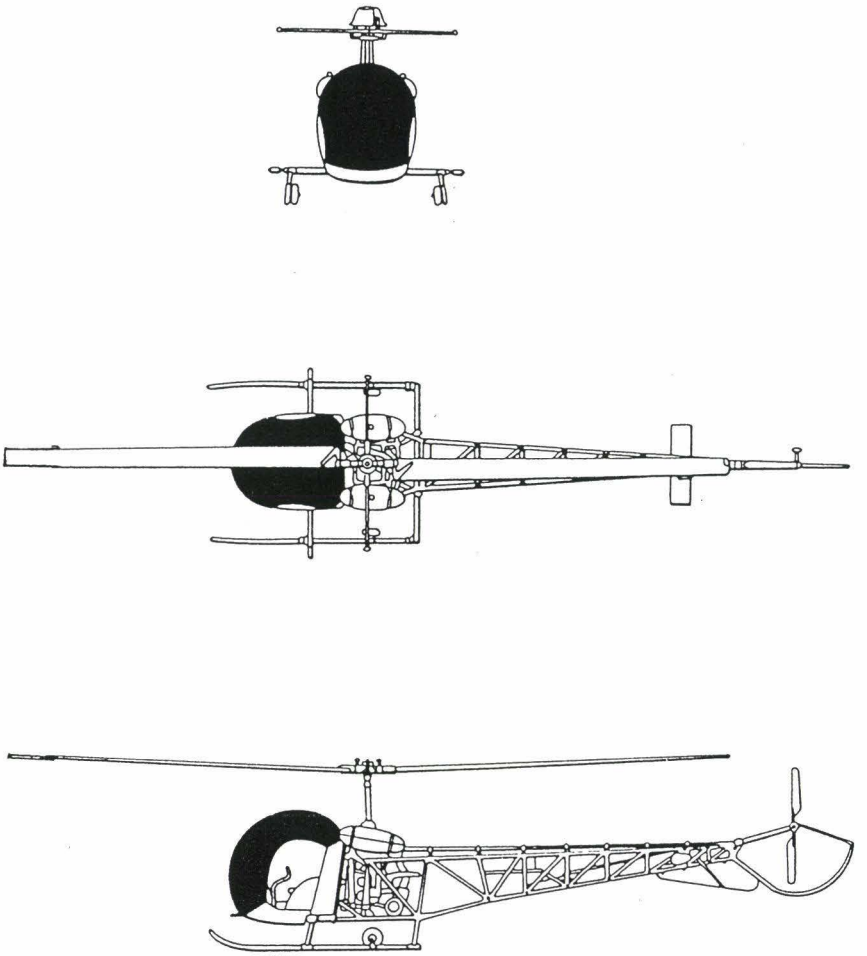

Figure 2-6: Schematic of the Bell 47G3B2 (Hardy, Ref. 13). Scale is approximately 1 cm = 1.2 m.

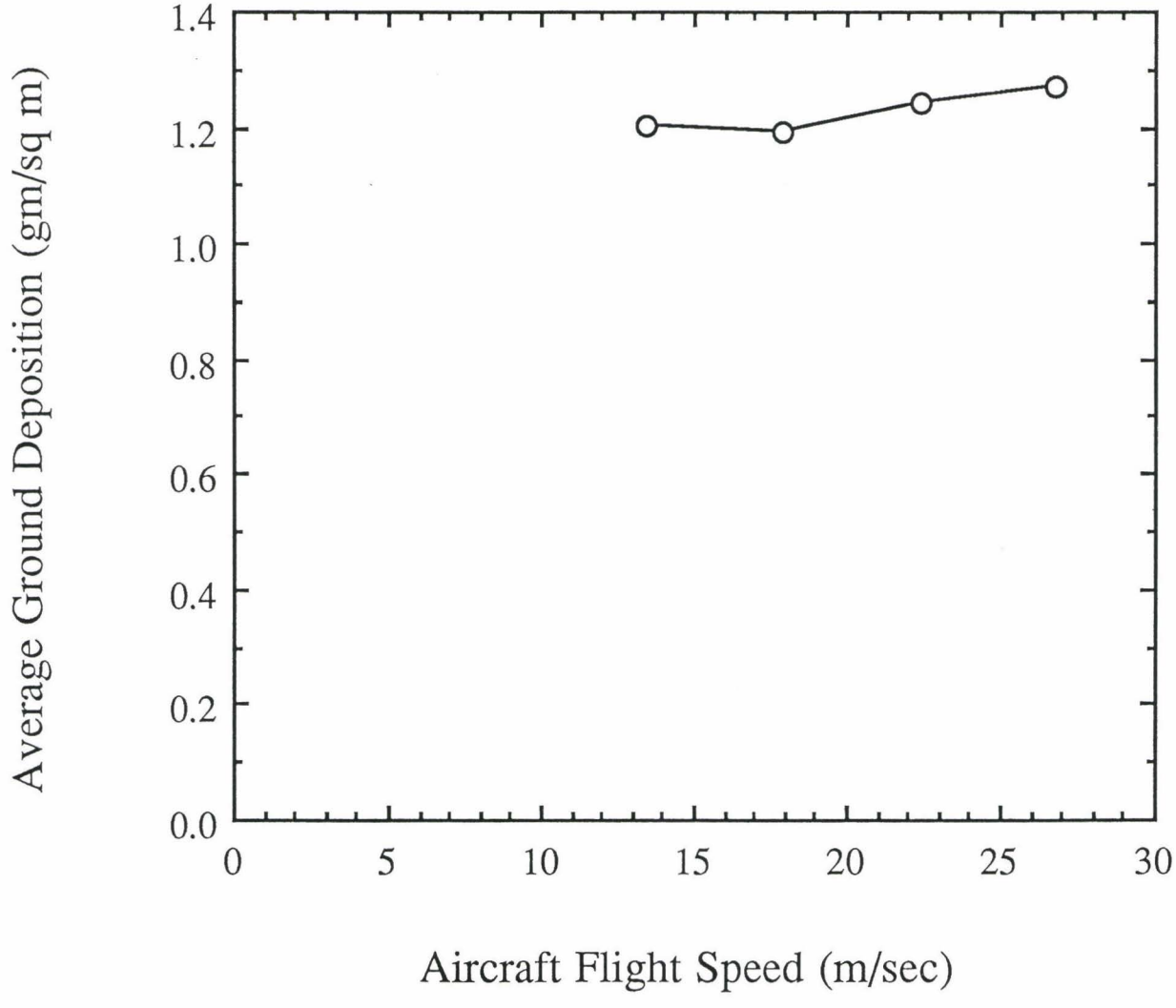

Figure 2-7: Average predicted ground deposition as a function of Aircraft Flight Speed for the Heather Seed Orchard canopy (June application). The nominal flight speed is 17.9 m/sec (40 mph).

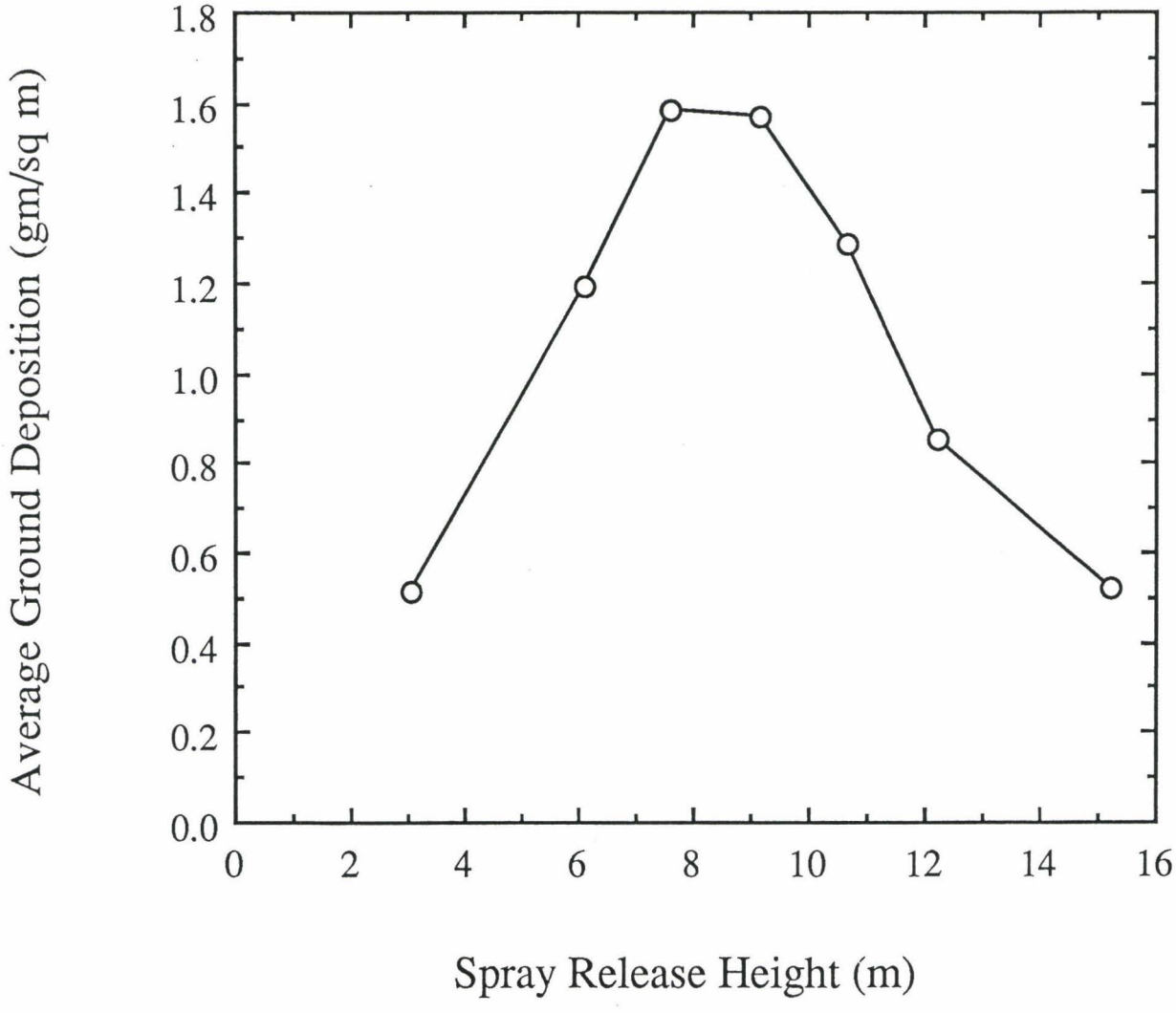

Figure 2-8: Average predicted ground deposition as a function of Spray Release Height above the Heather Seed Orchard canopy (June application). The nominal release height is 6.1 meters (20 feet above the canopy).

Table 2-3

D4-45 Nozzle Drop Size Distribution

(Data from Yates, et al., Ref. 14)

Lower Diameter (microns)	Mean Diameter (microns)	Upper Diameter (microns)	Mass Fraction
89.0	106.4	122.0	0.0249
122.0	138.6	154.0	0.0783
154.0	171.0	187.0	0.0954
187.0	203.4	219.0	0.1156
219.0	235.9	252.0	0.1201
252.0	268.3	284.0	0.1115
284.0	301.3	318.0	0.1119
318.0	334.8	351.0	0.1009
351.0	366.7	382.0	0.0714
382.0	398.2	414.0	0.0566
414.0	430.7	447.0	0.0438

Total mass fraction included = 0.9304

Volume median diameter (VMD) = 263.6 microns

Table 2-4

Symmetrical Nozzle Placement

All measurements are from the centerline of the helicopter.
Spray boom is positioned 2.46 m below the rotor plane.

Actual Location (m)	Modeled Location (m)
	0.0
0.17	
0.50	
	0.65
0.81	
1.22	
	1.30
1.38	
1.70	
	1.79
1.88	
2.19	
	2.28
2.36	
2.68	
	2.76
2.85	
3.16	
	3.25
3.33	
3.66	
	3.73
3.81	
4.14	
	4.31
4.47	

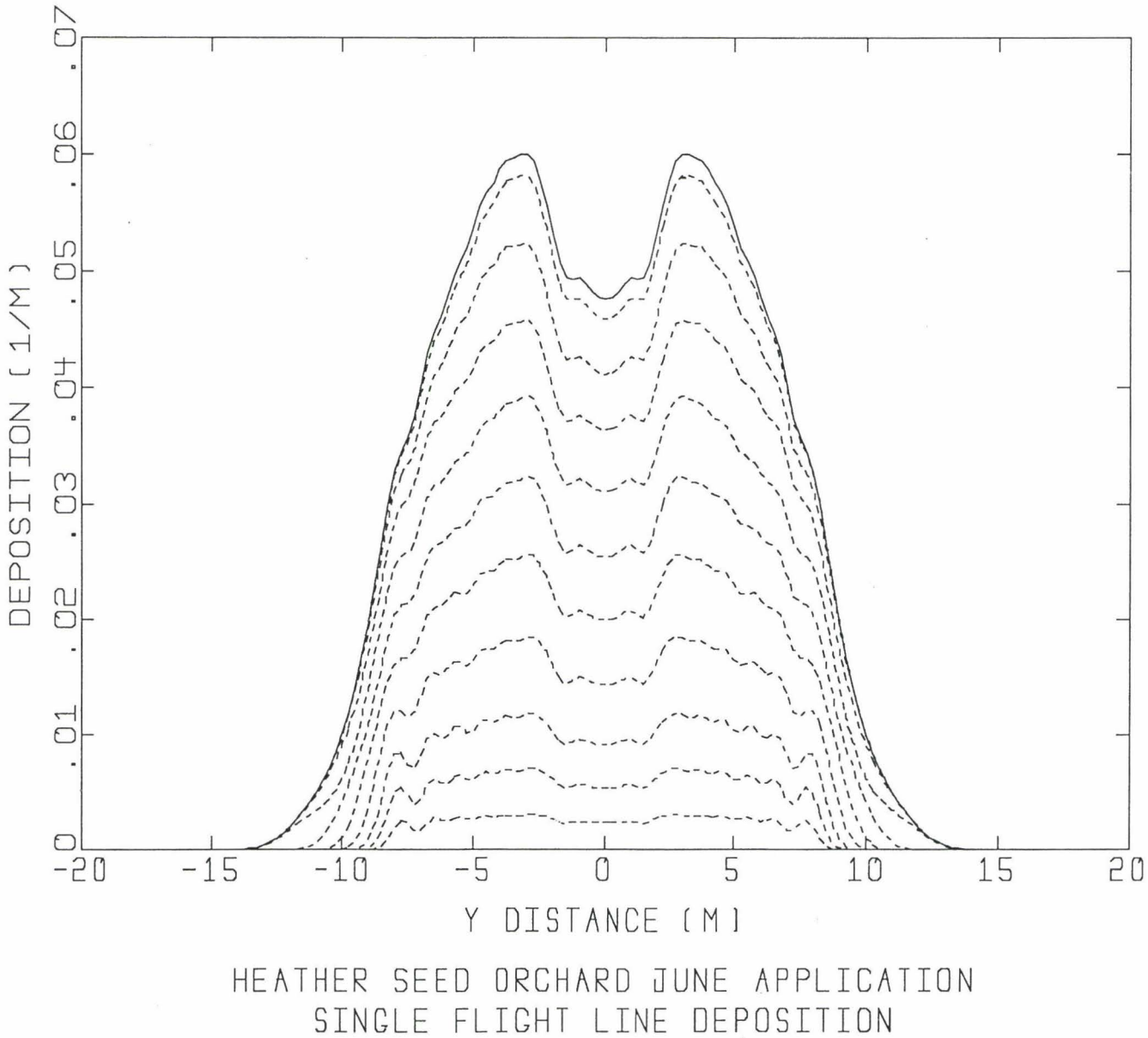

Figure 2-9: Top of canopy deposition pattern from one aircraft pass 6.1 meters above the Heather Seed Orchard canopy (June application). Solid line is total deposition; dashed lines indicate contributions by drop sizes. The swath width is seen to be approximately 18 meters, and may be taken at the nominal value of 18.3 meters (60 feet).

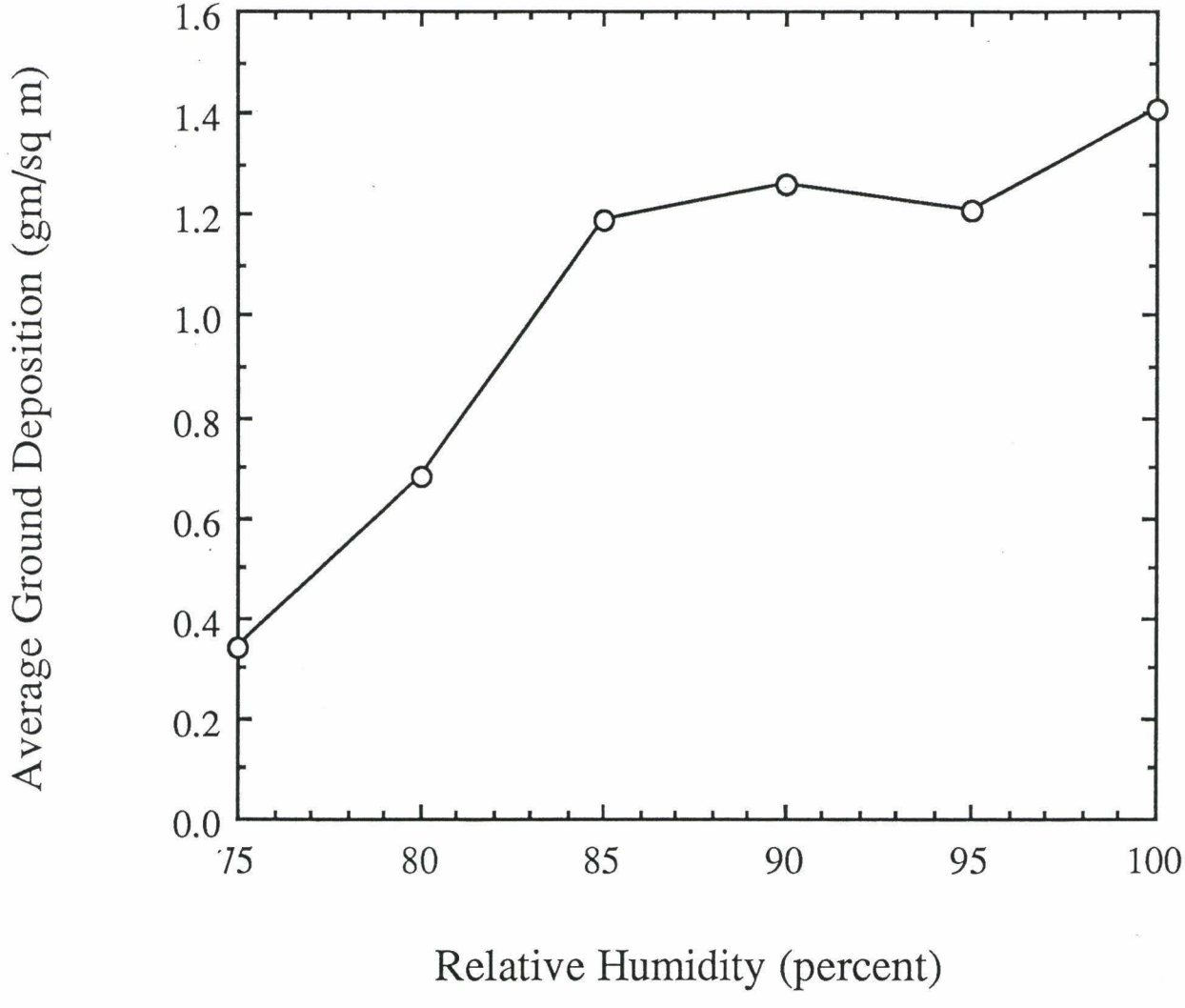

Figure 2-10: Average predicted ground deposition as a function of Relative Humidity for the Heather Seed Orchard (June application). The nominal relative humidity is 85 percent.

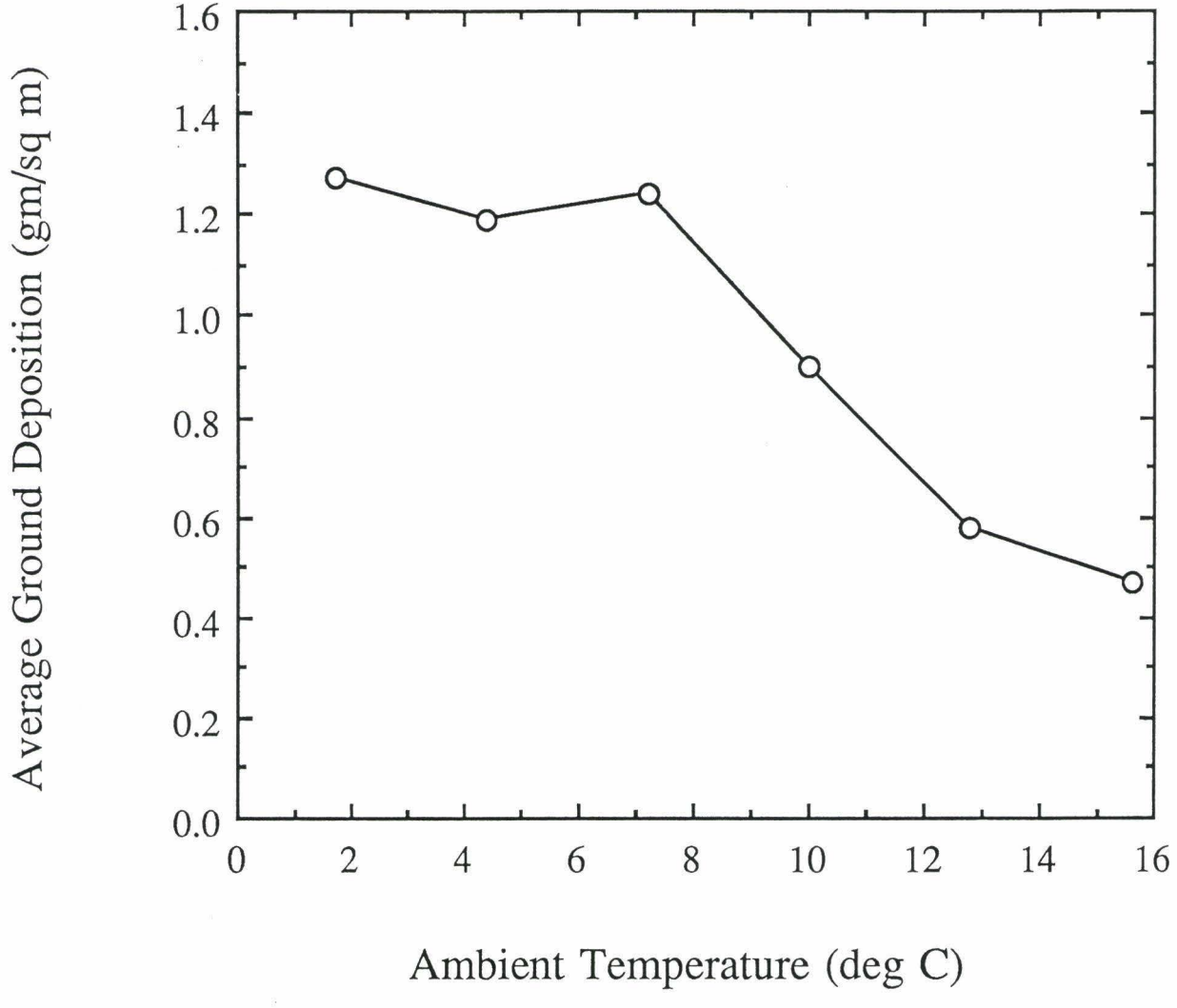

Figure 2-11: Average predicted ground deposition as a function of Ambient Temperature for the Heather Seed Orchard (June application). The nominal temperature is 4.4 deg C (40 deg F).

3. RESULTS

FSCBG predictions were made after each of the June and July spray applications at the Heather Seed Orchard for the conditions summarized previously in Table 2-1 (conditions existing at time of treatment) and:

(1) 25 stems per acre to predict deposition in the sparse tree stand area;

(2) 120 stems per acre to predict deposition in the dense tree stand area; and

(3) No canopy to predict deposition without trees.

Figures 3-1 to 3-4 show FSCBG predictions consistent with the pretest predictions in Figures A-3 to A-6. The considerably higher actual values of relative humidity during the spray applications result in a more uniform deposition distribution across the flight lines at the top of the canopy (Figure 3-1 for the June application and Figure 3-2 for the July application), and at the ground (Figure 3-3 for the June application and Figure 3-4 for the July application). The maximum predicted pretest deposition values at the top of the canopy are nearly equal to the predictions for June and July with the actual measured relative humidities. The pretest ground deposition values are considerably lower than the June and July predictions because of the relative humidity effect. More deposition is predicted in the July application than in the June application because the higher July relative humidity reduces the amount of evaporation.

Figures 3-1 to 3-4 also show that deposition is independent of position along the flight lines when inside the spray area. Since all sample trees were within the spray area as well, the comparisons that follow will plot deposition as a function of cross flight line distance (the vertical scale in Figures 3-1 to 3-4).

Card data were collected around ten representative trees in each of the sparse and dense tree stand areas (Bentson, Ref. 7; trees indicated in Figure 2-1; card locations shown schematically in Figure 3-5). Cards were placed in the four cardinal directions at zero meters (next to the tree trunk); two meters out, and five meters out. Deposition on the zero meter cards was minimal, indicating that at the trunk all material was effectively stopped before reaching the ground. The two-meter locations are seen to reflect the typical canopy behavior, while the five-meter locations (in the sparse tree stand area) reflect an open orchard without trees. Table 3-1 summarizes the following discussion.

Figure 3-6 gives the June and July comparisons for the two-meter locations for the sparse tree stand area. Here, and in the following figures, the northern side of the orchard is set as the origin; these plots are across the flight lines looking westward. Data around each tree are averaged to give one data point plotted on the appropriate figure. This averaging eliminates the effect of aircraft direction on the data.

Table 3-1 indicates that the average ground deposition predicted by FSCBG (sparse) and the average of all two-meter data in the sparse tree stand area are nearly equal. This result confirms several FSCBG input assumptions about the June and July applications:

(1) The average canopy shape (given in Table 2-2) represents the Douglas-fir canopy structure in the Heather Seed Orchard. The strong sensitivity to canopy height (Figure 2-2) suggests that the assumed height of 15 meters is also consistent with the Heather Seed Orchard.

(2) The assumed value of stand density in the sparse tree stand area (25 stems per acre) is consistent with the Heather Seed Orchard.

(3) The assumed value of penetration probability (0.38) is consistent with the Heather Seed Orchard.

(4) The spray release height of 6.1 meters (20 feet) represents the June and July spray applications in the Heather Seed Orchard. Bentson, et al. (Ref. 10) suggest that the aircraft release height was higher than nominal. FSCBG agreement with data in Figure 3-6 could not have been achieved with the sensitivity of average ground deposition with spray release height (Figure 2-8) unless the height was assumed correctly.

Figure 3-7 gives the June and July comparisons for the two-meter locations in the dense tree stand area. In the FSCBG predictions the stand density was increased to 120 stems per acre without changing any other inputs. Table 3-1 indicates that the average ground deposition predicted by FSCBG (dense) and the average July application data are nearly equal. Because the ratios of average ground deposition in July to average ground deposition in June (third column in Table 3-1) are consistent for the two-meter and five-meter data points except for the June application in the dense tree stand area, it is here suggested that the June dense tree stand deposition data may be in error. A reduction of the July dense tree stand deposition data by 1.40 gives an extrapolated June deposition level of 0.153, approaching the corresponding FSCBG (dense) prediction for June.

The agreement with data in the dense tree stand area would suggest that the FSCBG penetration probability model input does not have to be changed when changing stand density.

Figure 3-8 gives the June and July comparisons for the five-meter locations in the sparse tree stand area with the assumption of no canopy in the FSCBG predictions. In the Heather Seed Orchard a distance of five meters from the trees generally placed the cards in the open. An indication of this effect could be obtained by running FSCBG without the presence of the Heather Seed Orchard canopy (open). Figure 3-8 illustrates that the no-canopy assumption may in fact be a good one. Table 3-1 confirms that the open prediction comparison is in very good agreement with the July application.

A conjecture that ground deposition increases exponentially from the tree trunks (K. P. Bentson, private communication) may be confirmed by plotting average ground deposition from the three conditions:

(1) Five meters out from the sparse stand tree trunks (looks like no canopy);

(2) Two meters out from the sparse stand (25 stems per acre) tree trunks; and

(3) Two meters out from the dense stand (120 stems per acre) tree trunks.

The semi-logarithmic plot is given in Figure 3-9 for both the June and July applications. A least squares curve fit gives:

$$\text{Average Ground Deposition} = A \exp (- B (\text{stems per acre}))$$

where

A = 2.49 (June application) and 3.49 (July application)

B = 0.023 (both applications)

The average ground deposition data appears to be correlated by the above expression. Deposition levels from the five meter locations in the dense tree stand area (from Table 3-1) are seen from Figure 3-9 to occur consistently at 60 stems per acre. Subsequent FSCBG calculation results (60 stems per acre) are also shown in Table 3-1.

During the Heather Seed Orchard applications, deposition cards were extended perpendicular to the aircraft flight path into the adjacent forest. Open terrain existed between the orchard and the forest on both sides of the spray area (Figure 2-1). Figure 3-10 gives the June and July comparisons for this drift data. It is conjectured from these comparisons that the aircraft was flown correctly, and minimal off-orchard drift occurred during the June and July applications. Overall, the off-target deposition is consistent with FSCBG predictions at the edge of the dispersion plume.

Foliage data were also collected through the canopy height for the June and July applications. For ease of presentation, data results (Bentson, Ref. 9) were prepared in the upper third, middle third and lower third of the canopy.

Bentson acknowledges that the foliage results are inconclusive (K. P. Bentson, private communication). The data does indeed exhibit larger variability than the ground deposition data. Bentson speculates that this variability is the result of differences in the tree canopies (sparse and dense sections), application spatial nonuniformity, and inability to position receptors and recover branch material particularly in the dense tree stand area (Bentson, Ref. 9). Deposition results were computed as amount of material per 80 needles analyzed for each data collection location. FSCBG comparisons are in deposition per area, and require conversion from number of needles. Although the Douglas-fir shows considerable variation with height with regard to needle surface area, it will be assumed that, on average, the area conversion may be taken to be:

30 cm^2 per 80 needles

(K. P. Bentson, private communication). The above number converts field data results to appropriate units for comparison with FSCBG predictions.

Figures 3-11 and 3-12 compare FSCBG predictions with the foliage data (each data point is averaged for the four cardinal directions around the tree). Figure 3-11 gives the sparse tree stand area results for 25 stems per acre and for open conditions. Figure 3-12 gives the dense tree stand area results for 120 stems per acre and for 60 stems per acre (the anticipated open area between the densely spaced trees at the Heather site).

Foliage predictions by FSCBG bracket the foliage data and are summarized in Table 3-2. It should be noted that FSCBG predicts the average deposition through the canopy, while the data is collected at specific locations in the canopy. FSCBG averages across the tree cross-section; thus, it is not surprising that the predictions are not as close to the data as with the ground deposition. The positions of the analyzed branches have a strong influence on the field data in this table. Table 3-2 indicates that more material was recovered on the foliage in the dense tree stand area than in the sparse tree stand area, particularly in the lower third of the canopy.

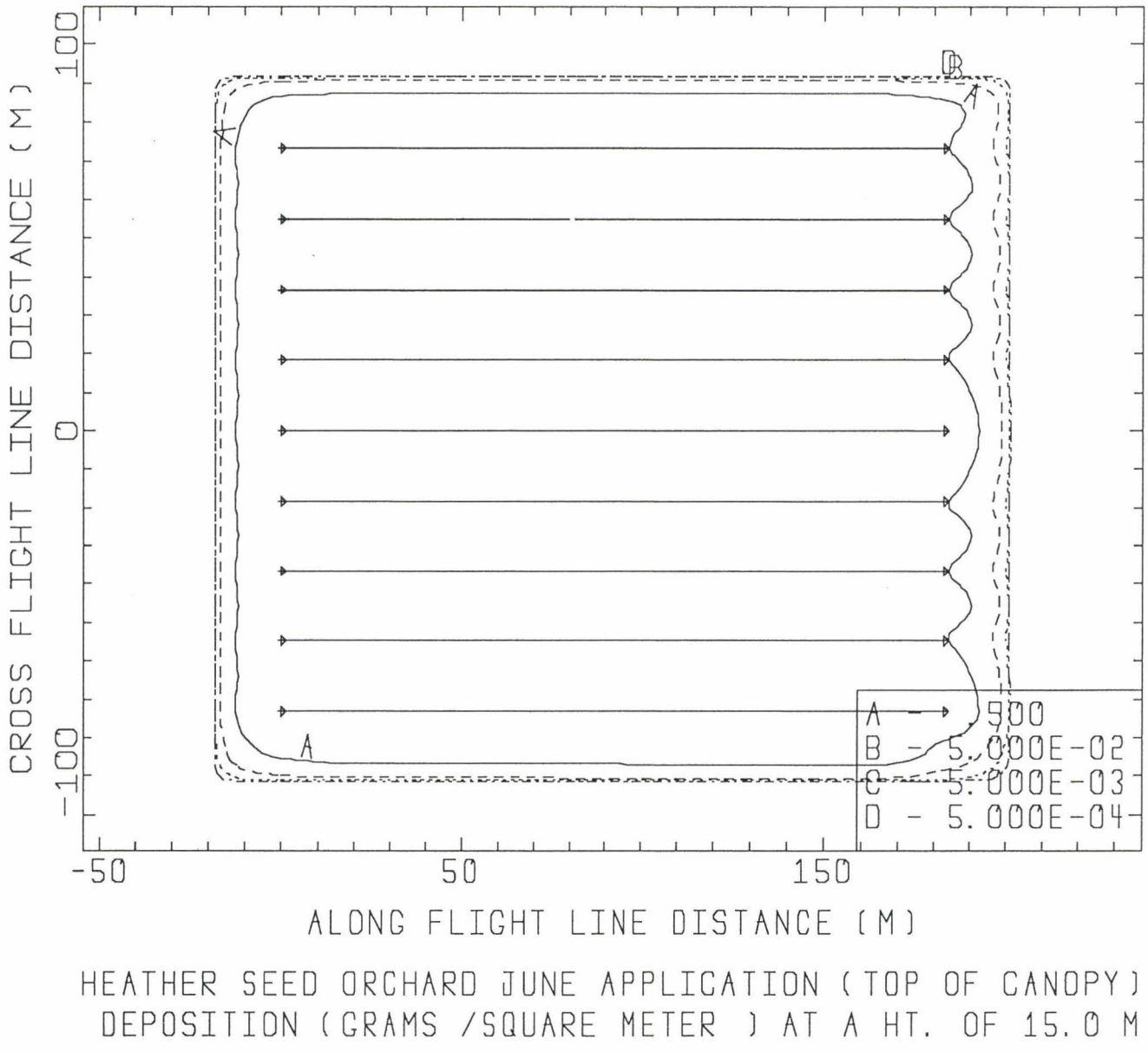

Figure 3-1: Deposition contours at the top of the Heather Seed Orchard canopy for the June application. Maximum predicted deposition is 4.11 gm/m^2. Contour levels of 0.5, 0.05, 0.005 and 0.0005 gm/m^2 are indicated.

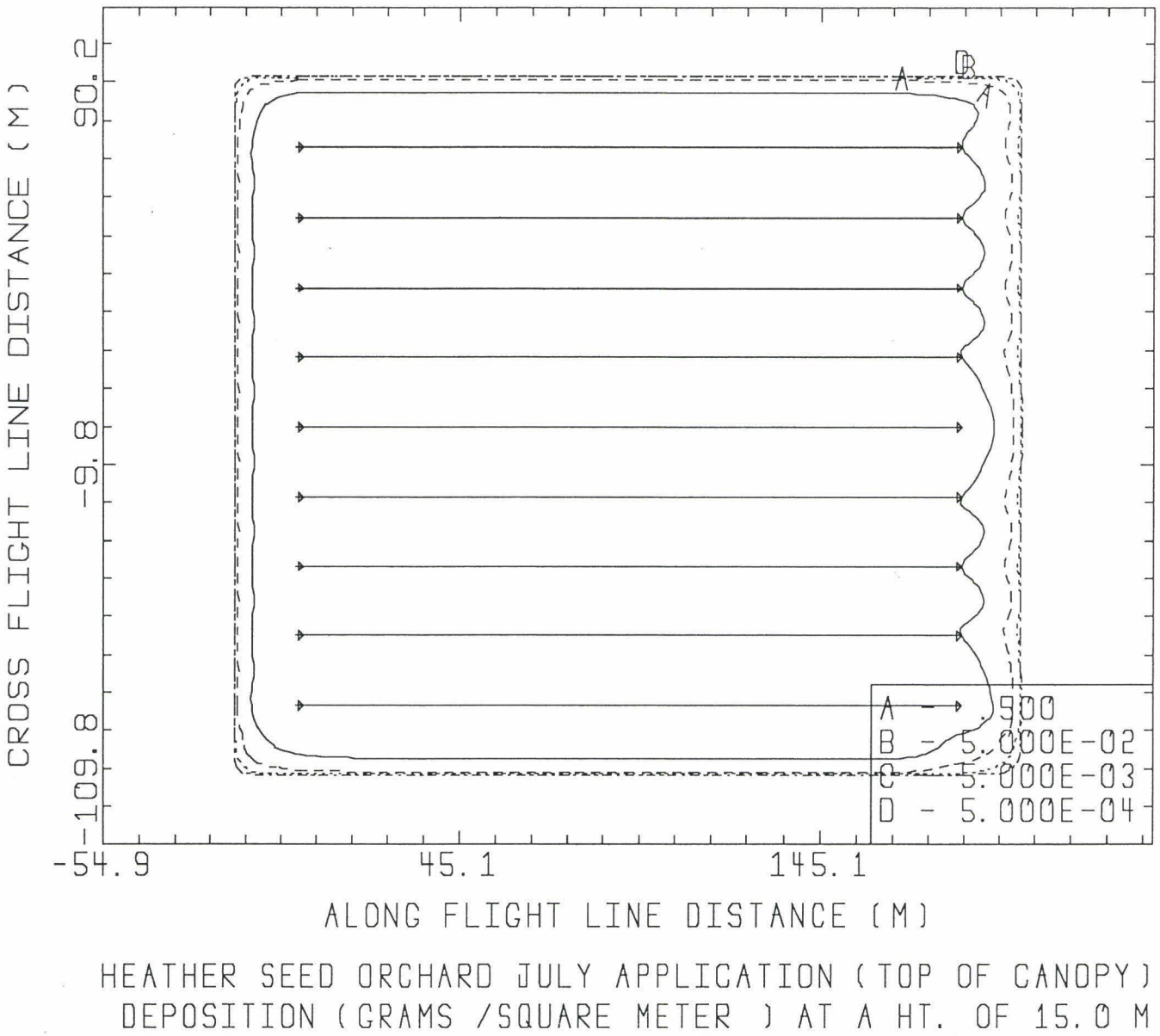

Figure 3-2: Deposition contours at the top of the Heather Seed Orchard canopy for the July application. Maximum predicted deposition is 4.19 gm/m^2. Contour levels of 0.5, 0.05, 0.005 and 0.0005 gm/m^2 are indicated.

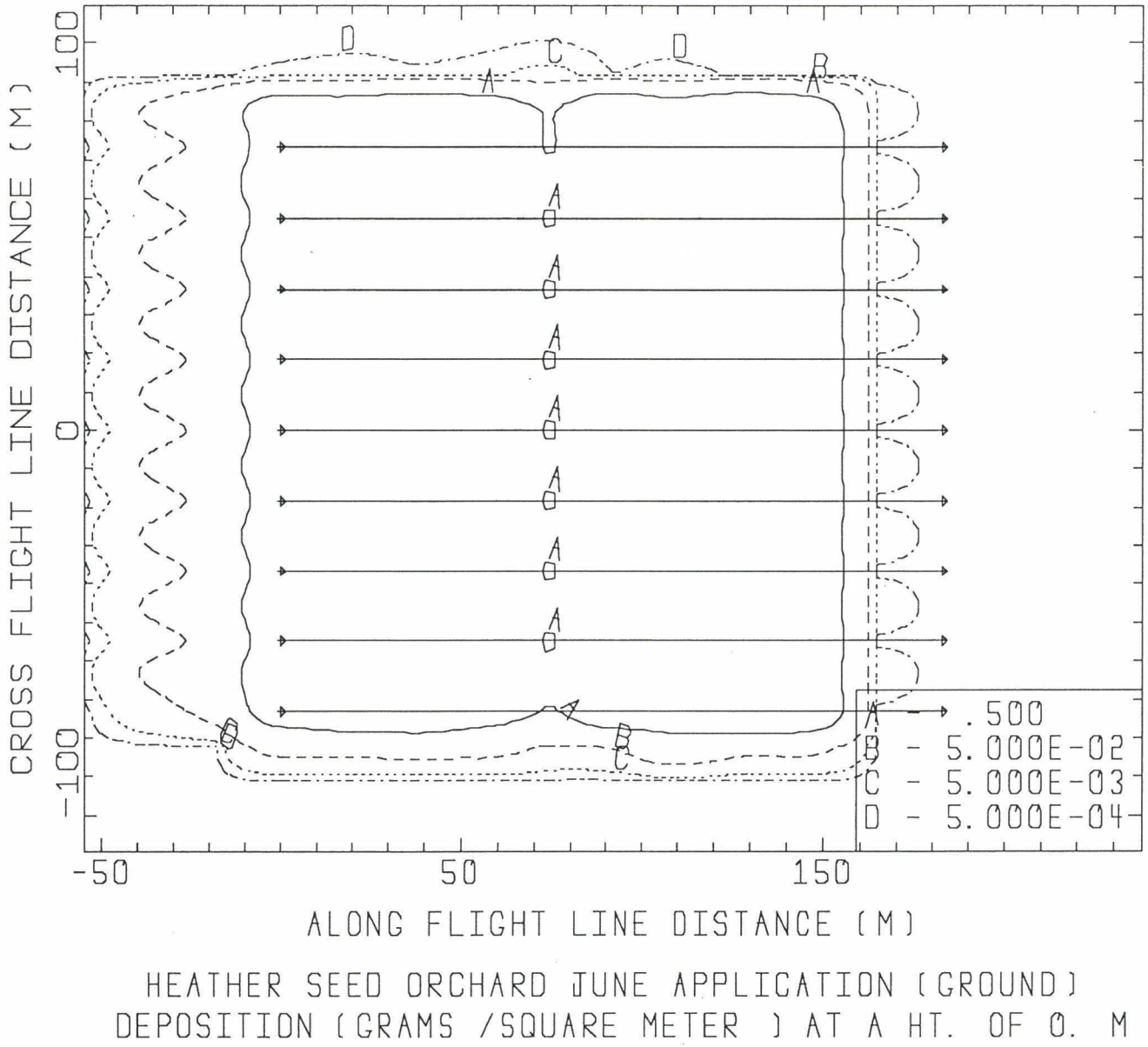

Figure 3-3: Deposition contours at the ground of the sparse tree stand area in the Heather Seed Orchard canopy for the June application. Maximum predicted deposition is 1.24 gm/m^2. Contour levels of 0.5, 0.05, 0.005 and 0.0005 gm/m^2 are indicated.

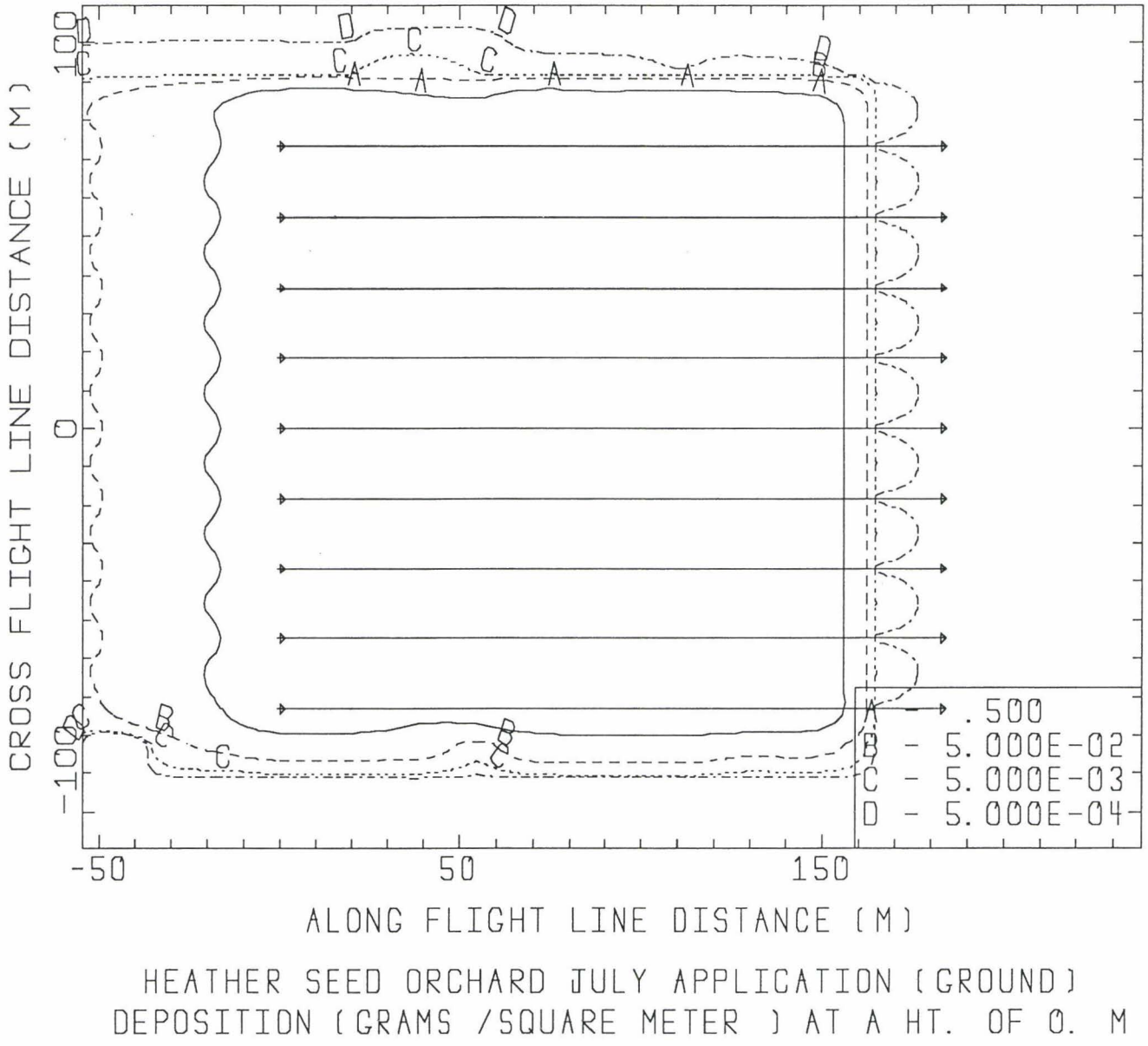

Figure 3-4: Deposition contours at the ground of the sparse tree stand area in the Heather Seed Orchard canopy for the July application. Maximum predicted deposition is 1.79 gm/m^2. Contour levels of 0.5, 0.05, 0.005 and 0.0005 gm/m^2 are indicated.

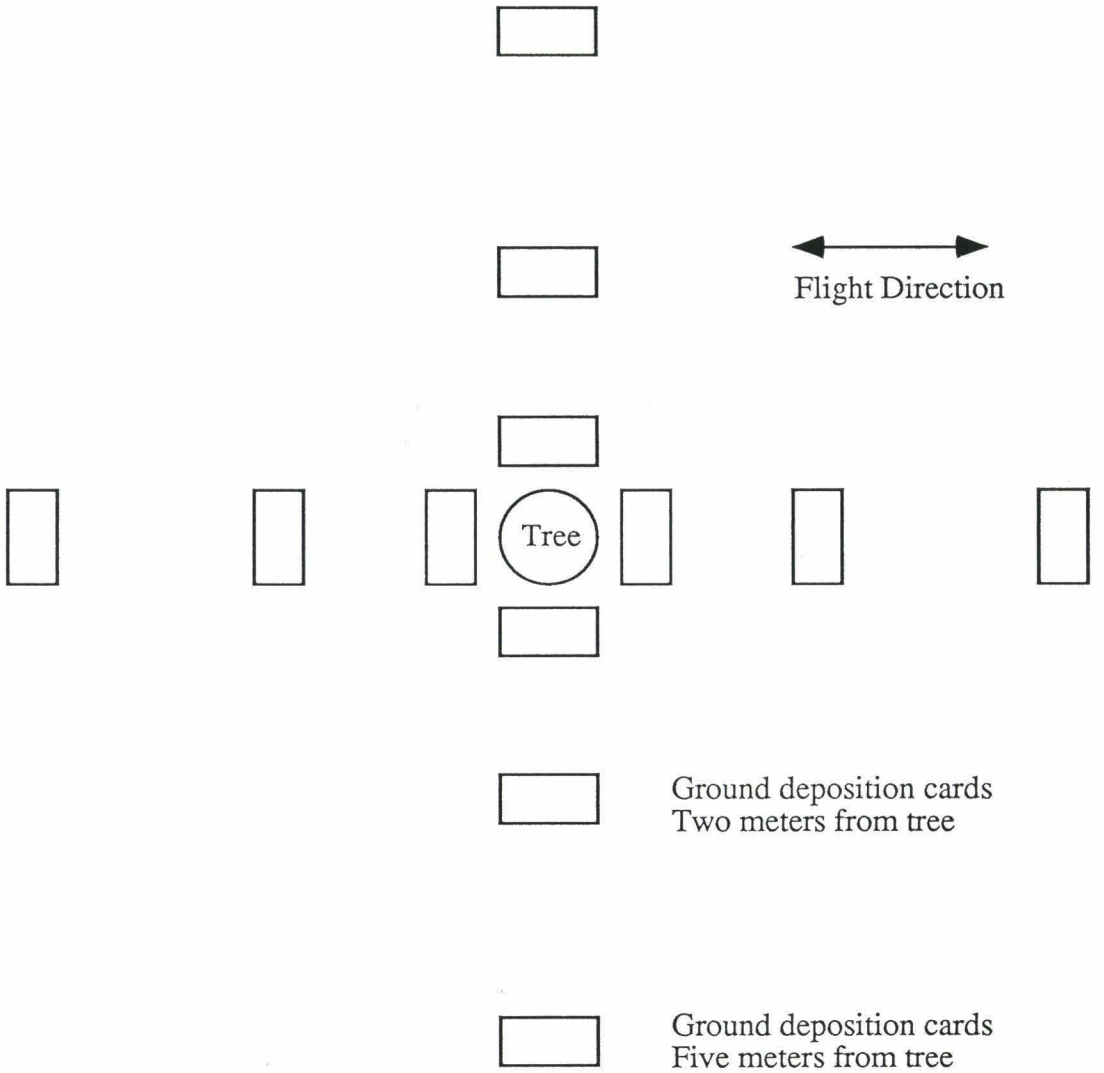

Figure 3-5: Placement of ground deposition cards around a sample Douglas-fir tree (after Bentson, Ref. 7).

Table 3-1

Average Deposition Levels (Ground)

(Data from Bentson, Ref. 9, in gm/m^2 on the ground)

	June	July	Data Ratio (July/June)
Sparse Tree Stand Area			
At tree trunk	0.159	0.319	
Two meters out	1.103	1.567	1.42
Five meters out	2.908	4.051	1.39
Dense Tree Stand Area			
At tree trunk	0.043	0.045	
Two meters out	0.101	0.214	2.12
Five meters out	0.575	0.801	1.39
FSCBG Predictions			
Sparse	1.19	1.47	
Dense	0.19	0.23	
Open	3.67	4.08	
60 stems per acre	0.62	0.77	

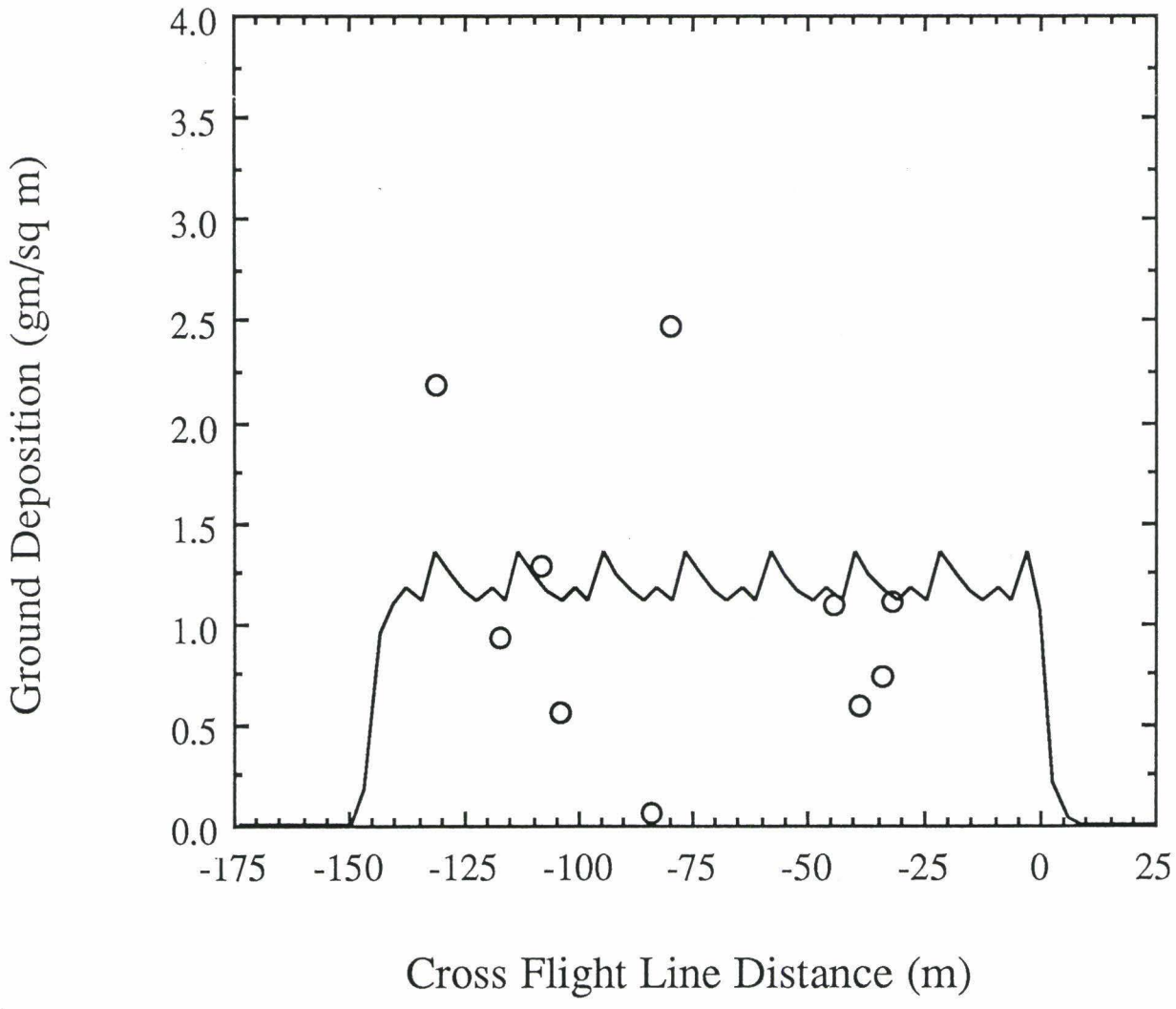

Figure 3-6: Ground deposition on cards set two meters from ten representative trees in the sparse tree stand area (circles), compared with the FSCBG prediction for a stand density of 25 stems/acre (solid line). (A) June application.

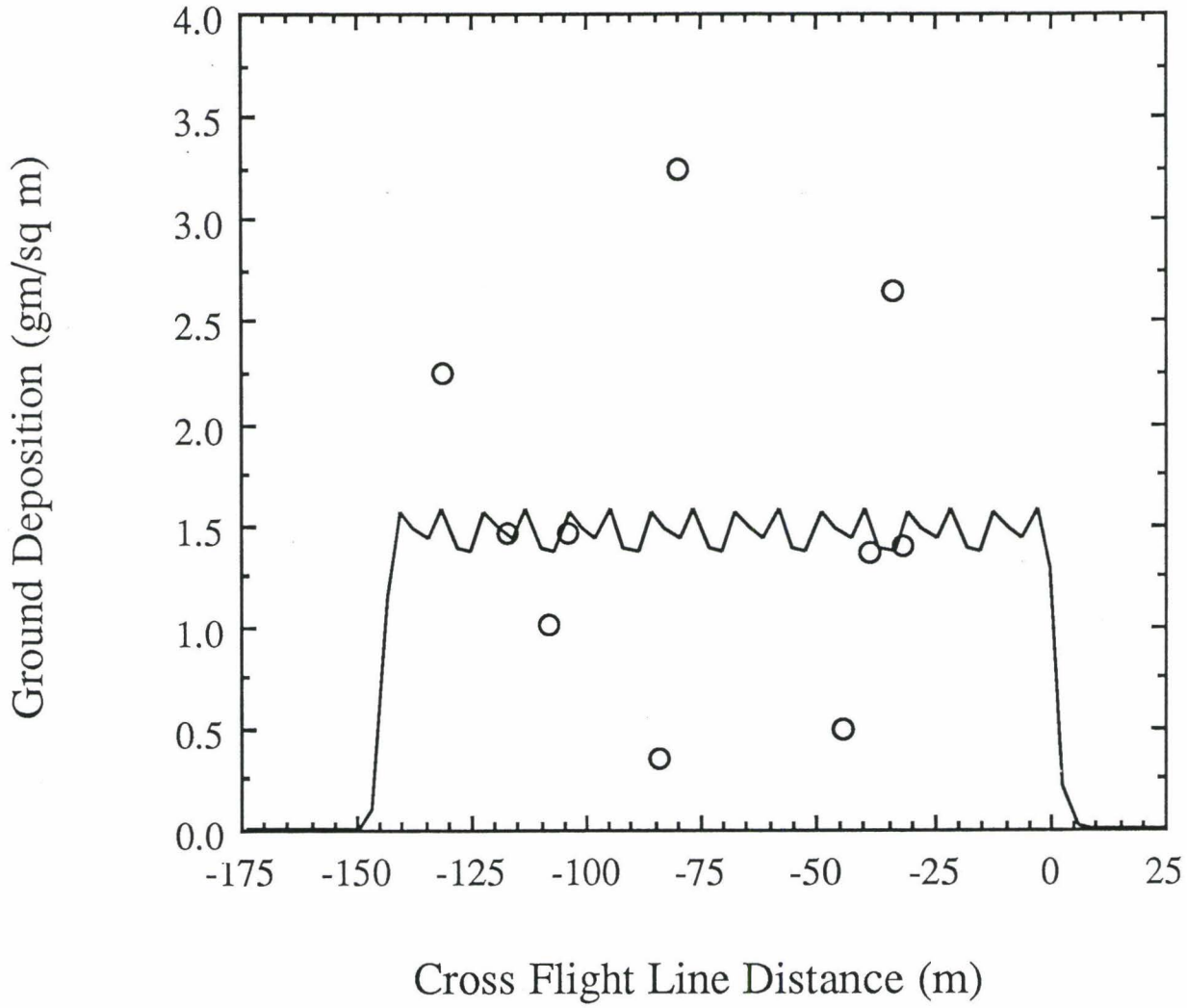

Figure 3-6 (Continued): Ground deposition on cards set two meters from ten representative trees in the sparse tree stand area (circles), compared with the FSCBG prediction for a stand density of 25 stems/acre (solid line). (B) July application.

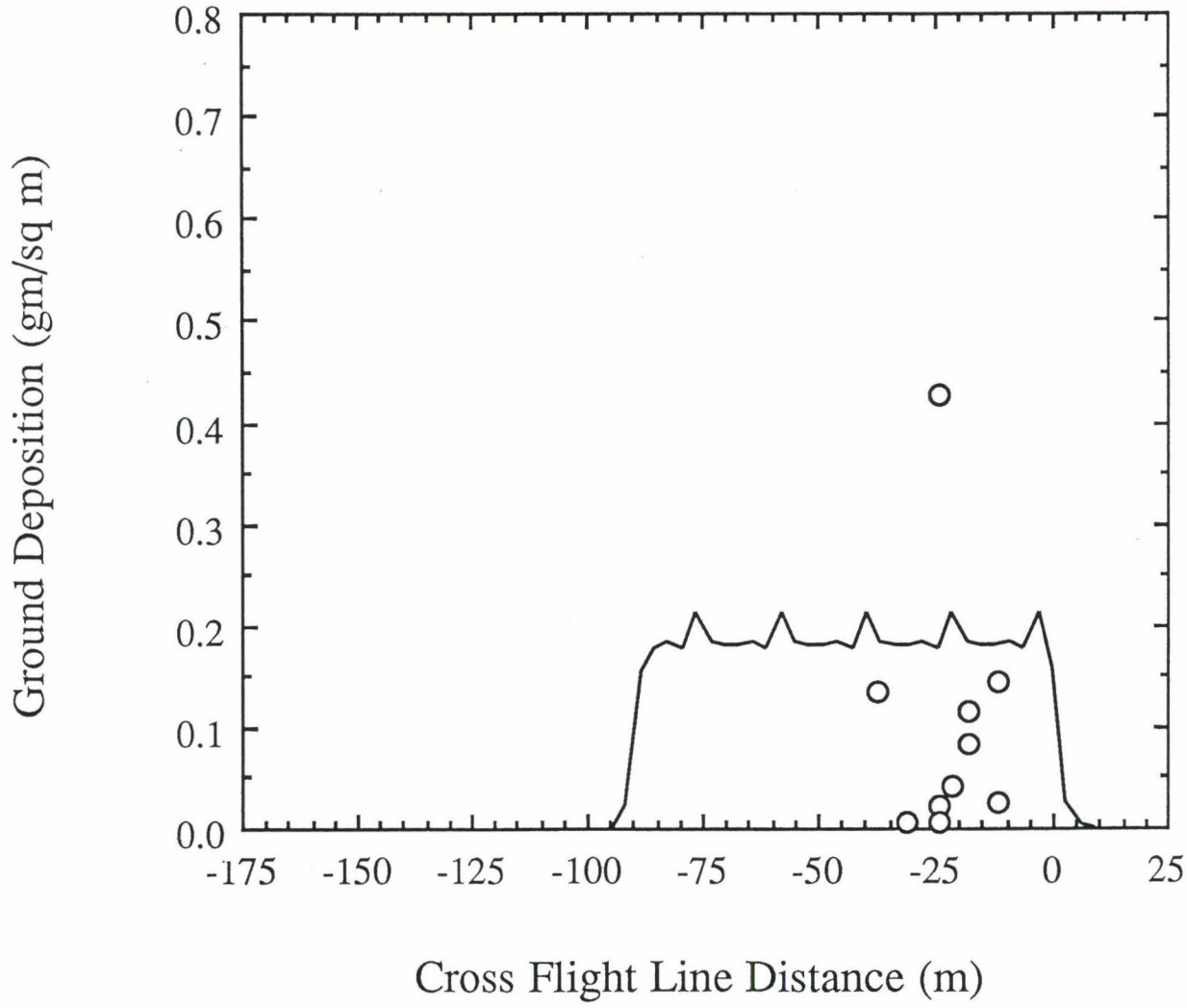

Figure 3-7: Ground deposition on cards set two meters from ten representative trees in the dense tree stand area (circles), compared with the FSCBG prediction for a stand density of 120 stems/acre (solid line). (A) June application.

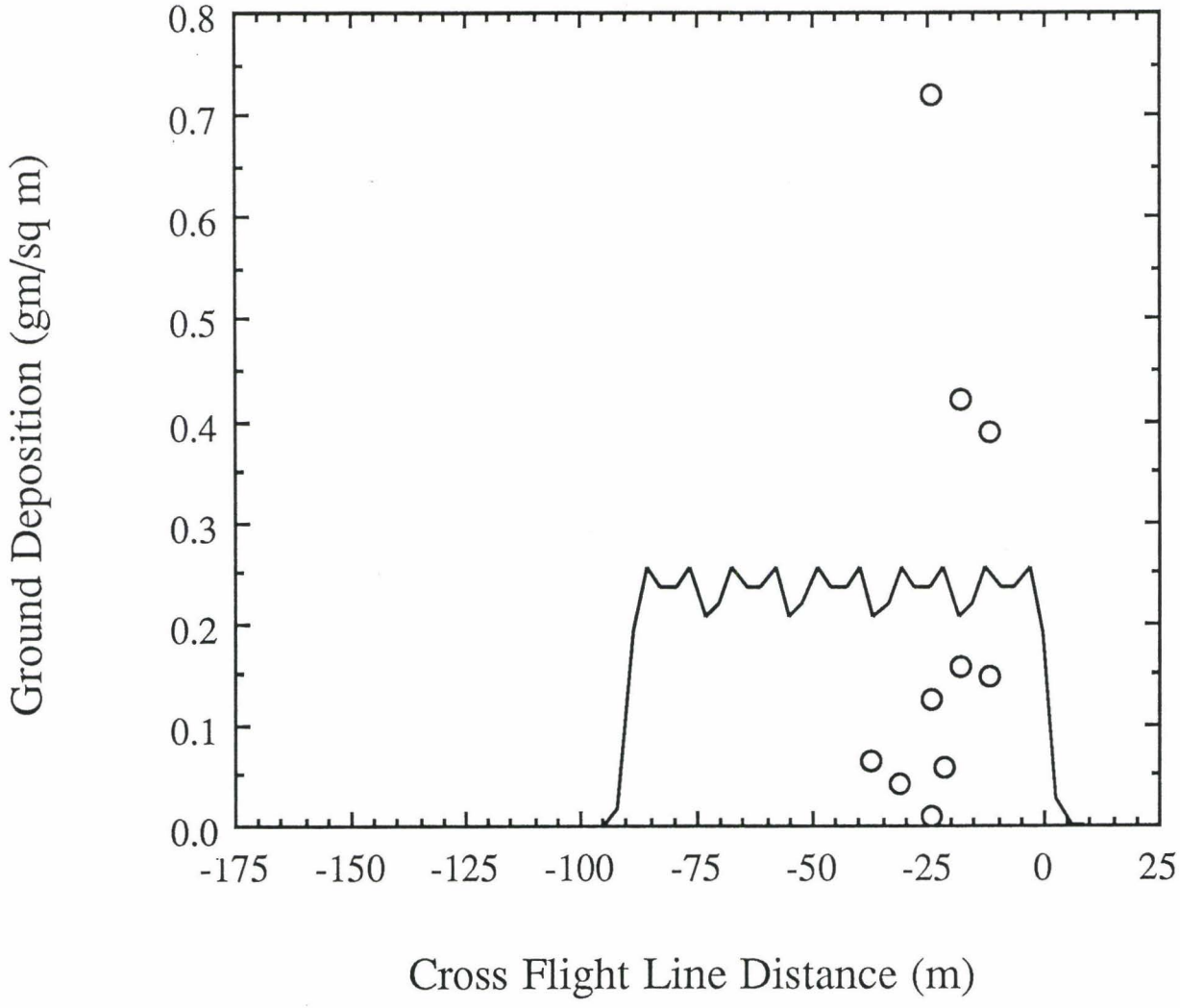

Figure 3-7 (Continued): Ground deposition on cards set two meters from ten representative trees in the dense tree stand area (circles), compared with the FSCBG prediction for a stand density of 120 stems/acre (solid line). (B) July application.

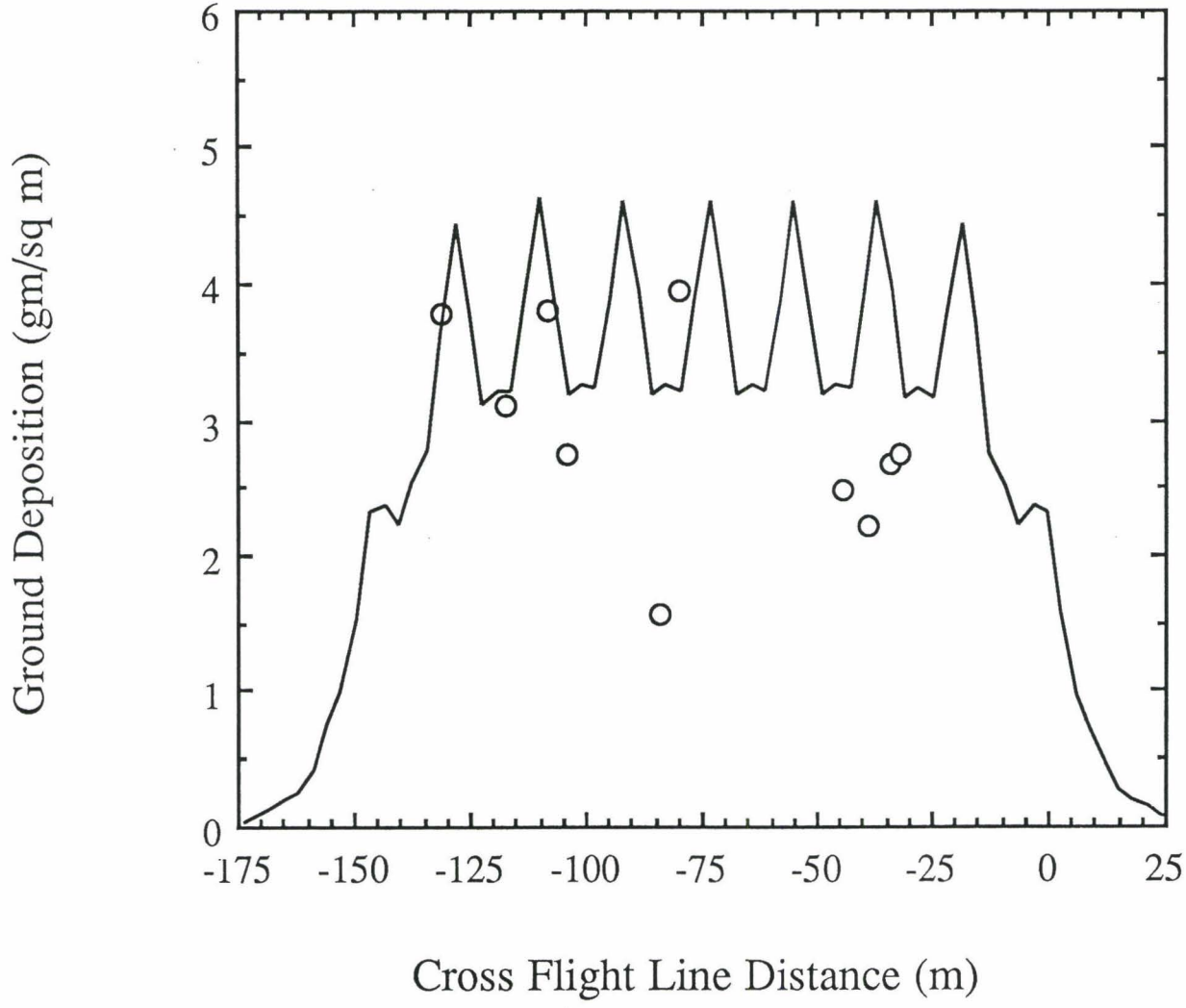

Figure 3-8: Ground deposition on cards set five meters from ten representative trees in the sparse tree stand area (circles), compared with the FSCBG prediction for no canopy (solid line). (A) June application.

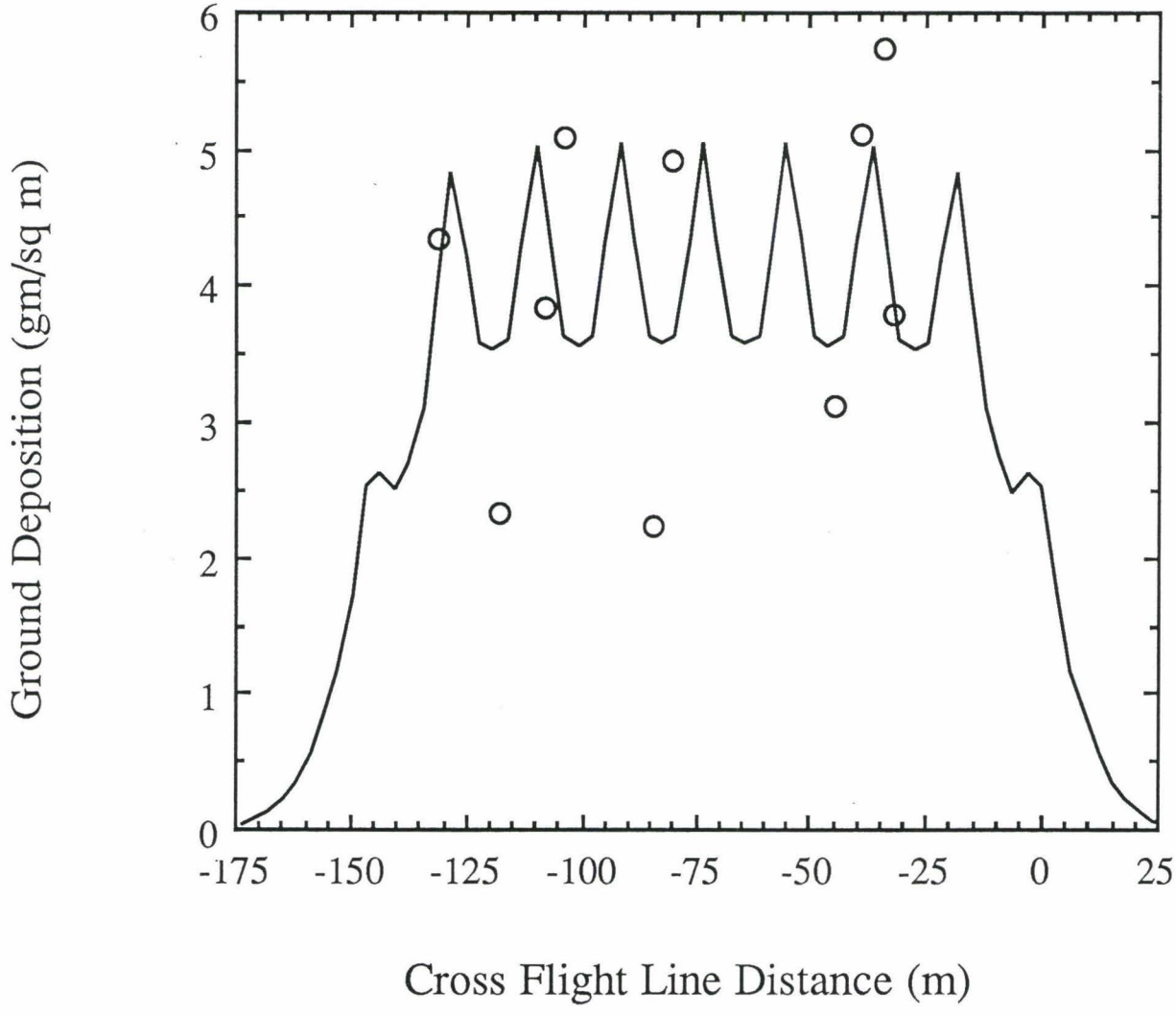

Figure 3-8 (Continued): Ground deposition on cards set five meters from ten representative trees in the sparse tree stand area (circles), compared with the FSCBG prediction for no canopy (solid line). (B) July application.

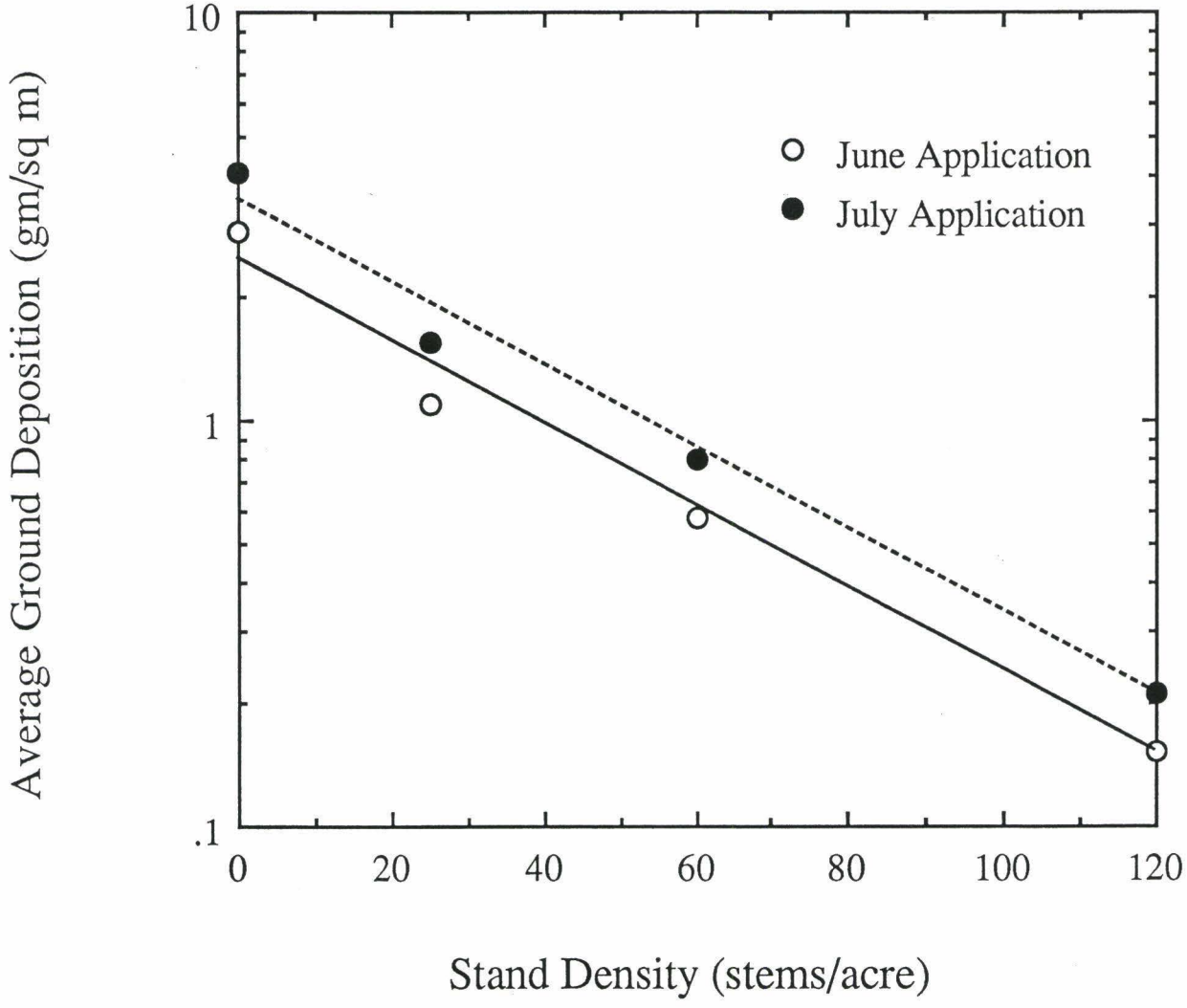

Figure 3-9: Average ground deposition on cards as a function of Stand Density (stems per acre). Open circles are averaged June application data; solid circles are averaged July application data. The two lines curve-fit the data exponentially (solid line for June application; dashed line for July application)

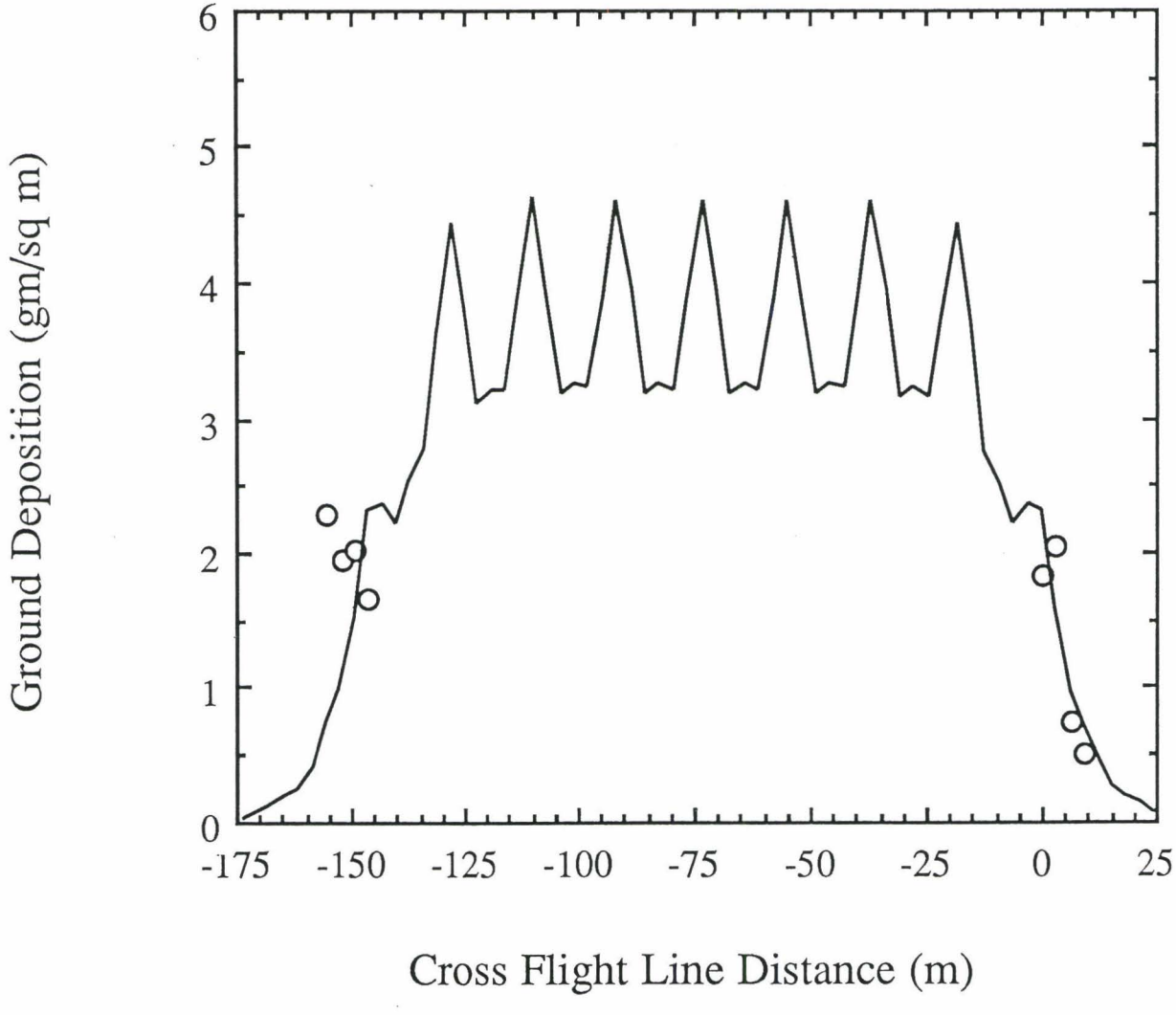

Figure 3-10: Ground deposition on cards across the spray boundaries (circles), compared with the FSCBG prediction for no canopy (solid line). (A) June application.

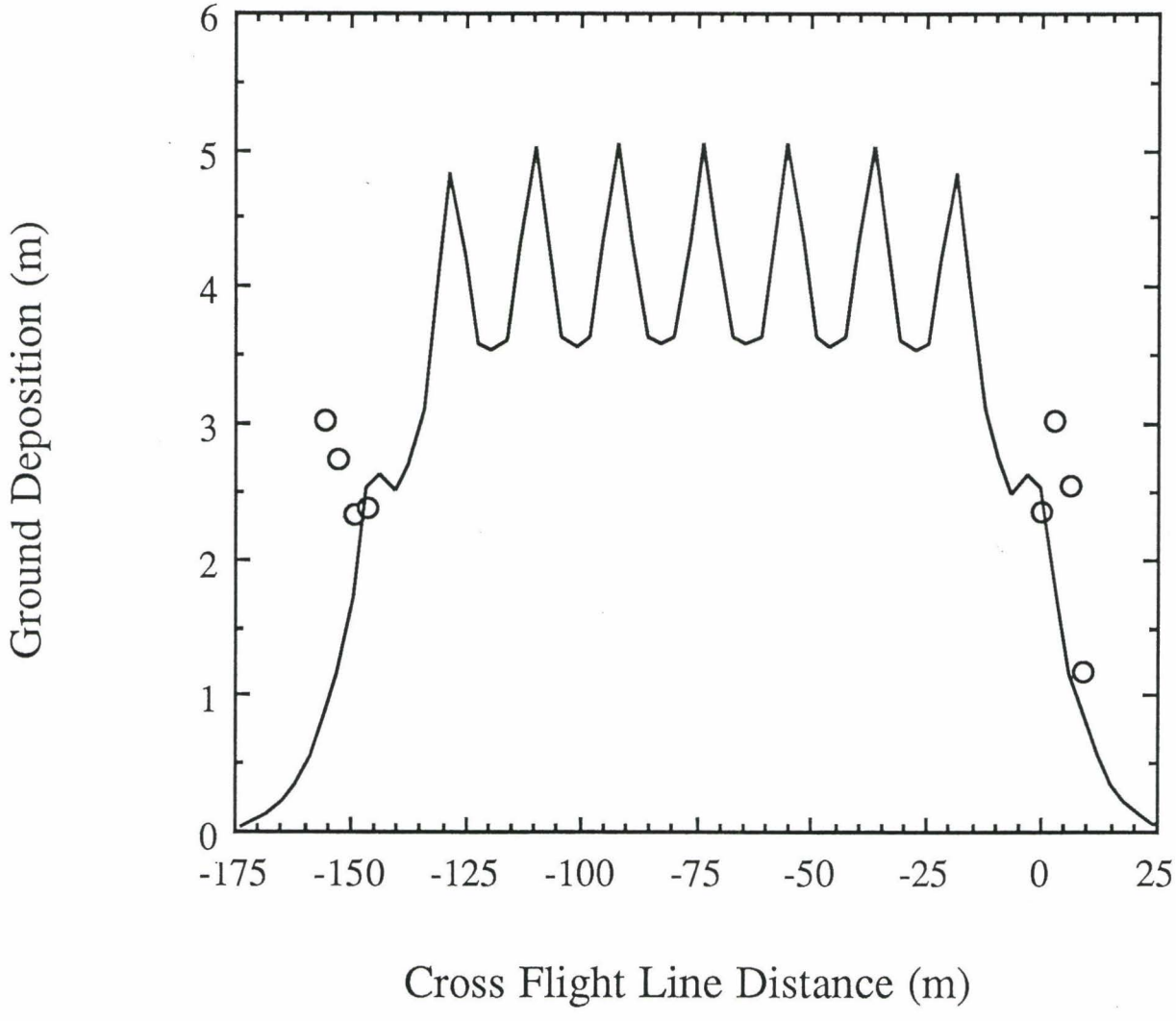

Figure 3-10 (Continued): Ground deposition on cards across the spray boundaries (circles), compared with the FSCBG prediction for no canopy (solid line). (B) July application.

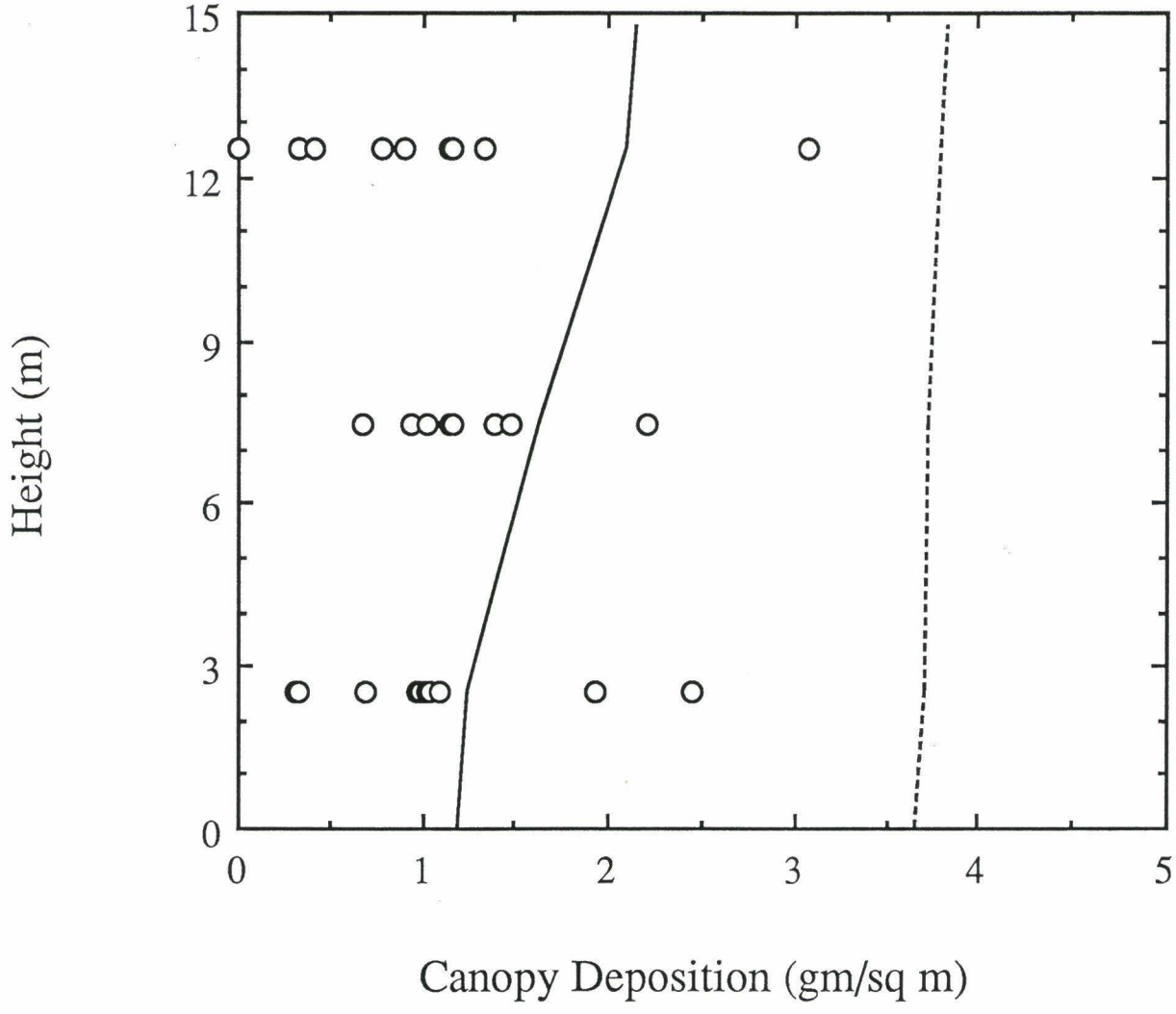

Figure 3-11: Deposition on foliage as a function of height through the sparse tree stand area in the Heather Seed Orchard canopy (circles), compared with the FSCBG predictions for a stand density of 25 stems/acre (solid line) and no canopy (dashed line). (A) June application.

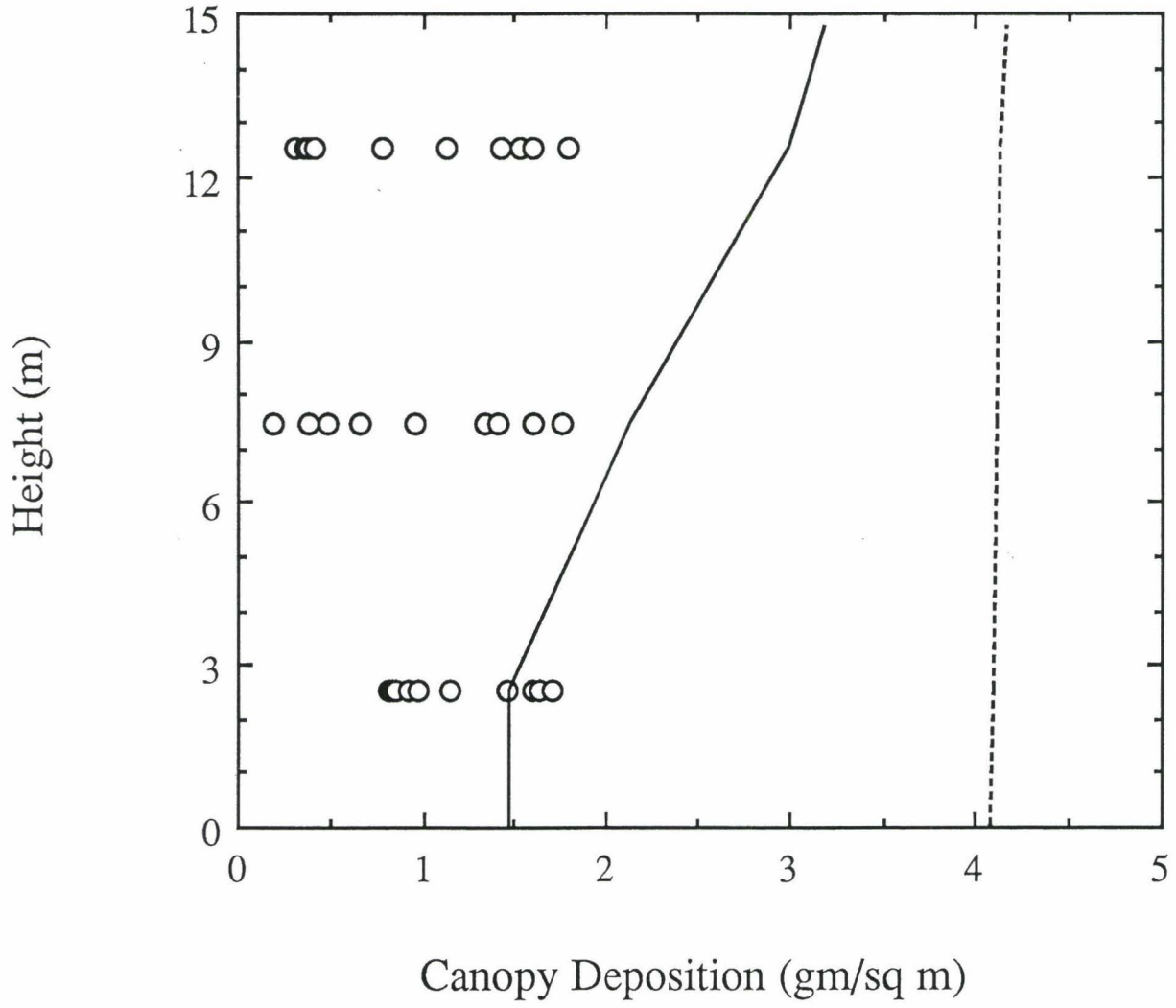

Figure 3-11 (Continued): Deposition on foliage as a function of height through the sparse tree stand area in the Heather Seed Orchard canopy (circles), compared with the FSCBG predictions for a stand density of 25 stems/acre (solid line) and no canopy (dashed line). (B) July application.

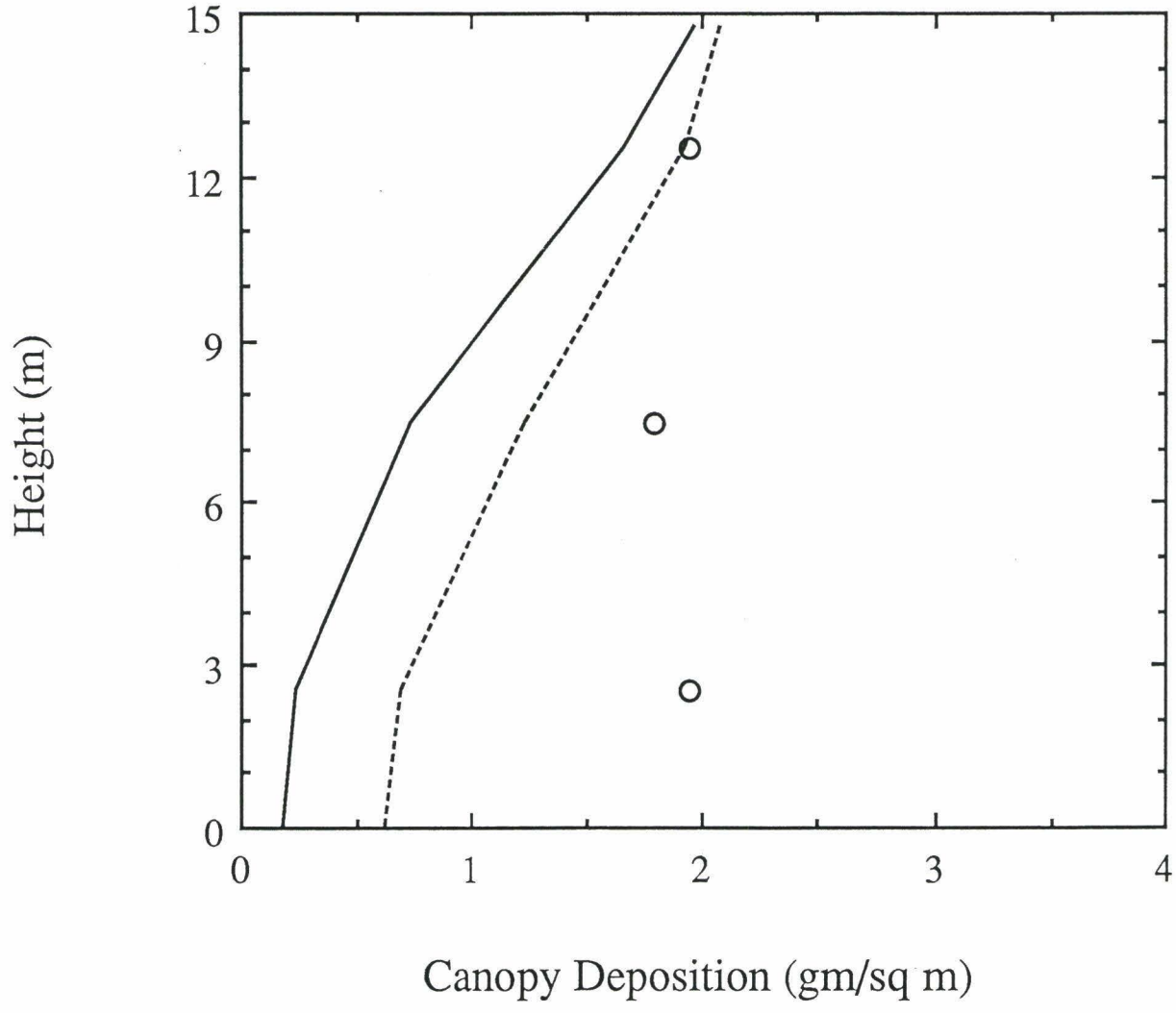

Figure 3-12: Deposition on foliage as a function of height through the dense tree stand area in the Heather Seed Orchard canopy (circles), compared with the FSCBG predictions for a stand density of 120 stems/acre (solid line) and 60 stems/acre (dashed line). (A) June application.

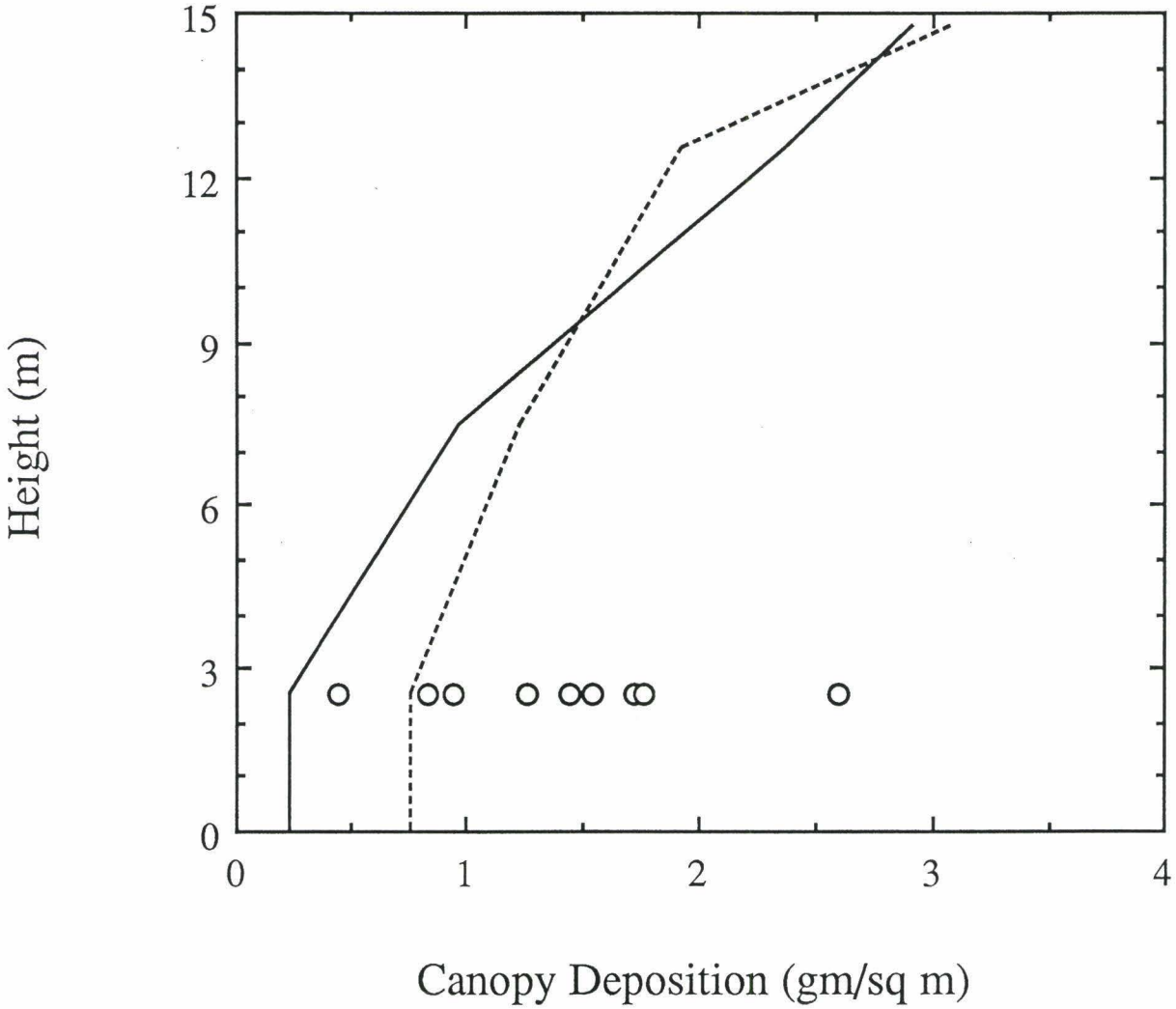

Figure 3-12 (Continued): Deposition on foliage as a function of height through the dense tree stand area in the Heather Seed Orchard canopy (circles), compared with the FSCBG predictions for a stand density of 120 stems/acre (solid line) and 60 stems/acre (dashed line). (B) July application.

Table 3-2

Average Deposition Levels (Foliage)

(Data from Bentson, Ref. 9, in gm/m^2 on the foliage)

	June	July
Sparse Tree Stand Area		
Lower third of canopy	1.09	1.19
Middle third of canopy	1.22	1.05
Upper third of canopy	1.12	0.97
Dense Tree Stand Area *		
Lower third of canopy	1.94	1.39
Middle third of canopy	1.79	-
Upper third of canopy	1.94	-
FSCBG Predictions		
Lower third of sparse canopy	1.25	1.26
Middle third of sparse canopy	1.63	2.13
Upper third of sparse canopy	2.10	3.00
Lower third of dense canopy **	0.69	0.70
Middle third of dense canopy **	1.23	1.61
Upper third of dense canopy **	1.93	2.76

* In the June application only one tree was instrumented; in the July application, only the lower third of the canopy was instrumented.

** 60 stems per acre.

4. CONCLUSIONS

The previous section of this report details qualitative model comparisons with data. Quantitative agreement may be seen by using the statistical analysis software described by Hanna (Ref. 16) to evaluate and compare model predictions with field data. The two measures of model performance used by this software are the Fractional Bias FB and the Normalized Mean Square Error NMSE. These performance measures are defined by:

$$FB = \frac{(\overline{C}_o - \overline{C}_p)}{0.5\,(\overline{C}_o + \overline{C}_p)}$$

$$NMSE = \frac{\overline{(C_o - C_p)^2}}{\overline{C}_o\,\overline{C}_p}$$

where C_o represents an observation, C_p represents a prediction, and the overbar indicates an average. Both FB and NMSE are equal to zero if there is perfect agreement between model predictions and field data.

Table 4-1 summarizes the application of these performance measures to the Heather Seed Orchard data and FSCBG model predictions. Average percent overprediction (Fractional Bias) is 8.3 percent for the Heather Seed Orchard data. This level of agreement is excellent, and points not only to the general usefulness of the FSCBG model, but also to the care taken in collecting and reducing the field data.

The average Normalized Mean Square Error is 0.449 for the Heather Seed Orchard data. The square root of this number gives a normalized RMS of 0.67 and indicates the significant scatter present in the field data.

The important observations for future experimental and operational use of FSCBG are the following:

(1) Inspection of the orchard is necessary to establish the canopy height, cross-sectional profile, stand density and penetration probability. The penetration probability does not change when moving from a sparse tree stand area to a dense tree stand area for Douglas-fir at the Heather Seed Orchard.

(2) Meteorological conditions must be measured accurately for wind speed, wind direction, ambient temperature and relative humidity . The usefulness of a portable meteorological tower cannot be understated.

(3) Douglas-fir data correlates with an exponential relationship to stand density (stems per acre), consistent with an average of the ground deposition data collected at the Heather Seed Orchard.

(4) Foliage data is more variable, but remains represented by FSCBG canopy predictions.

(5) The FSCBG model predicts canopy penetration and ground deposition through a Douglas-fir canopy to within an average of 8.3 percent as indicated by the Fractional Bias performance measure.

Table 4-1

Quantitative Comparison of Data with FSCBG Predictions

(Statistical model from Hanna, Ref. 16)

	June	July	
Fractional Bias			
Sparse tree stand area (2 meters)	-0.076	0.064	
Dense tree stand area (2 meters)	-0.217 *	-0.072	
Sparse tree stand area (5 meters)	-0.232	-0.007	
Dense tree stand area (5 meters) **	-0.075	0.039	
Overall average			-0.080
Average percent overprediction			8.3
NMSE			
Sparse tree stand area (2 meters)	0.375	0.329	
Dense tree stand area (2 meters)	0.860	0.944	
Sparse tree stand area (5 meters)	0.104	0.080	
Overall average			0.449
Normalized RMS			0.67

* Corrected for possible data error.

** 60 stems per acre.

A positive value of Fractional Bias implies that the model underpredicts the data on average, while a negative value implies that the model overpredicts the data on average.

5. REFERENCES

1. T. B. Curbishley and P. J. Skyler 1989: "Forest Service Aerial Spray Computer Model - FSCBG (PC) User Manual for Version 3.04," U. S. Department of Agriculture Forest Service Forest Pest Management Report No. FPM 89-1.

2. M. E. Teske 1988: "AGDISP User Manual Mod 5.0,: Continuum Dynamics, Inc. Technical Note No. 88-09.

3. D. G. Boyle, J. W. Barry, C. O. Eckard, W. T. Taylor, W. C. McIntyre, R. K. Dumbauld and H. E. Cramer 1975: "DC-7B Aircraft Spray System for Large-Area Insect Control," U. S. Army Dugway Proving Grounds DPG-DR-C980A.

4. J. E. Rafferty, R. K. Dumbauld, H. W. Flake, J. W. Barry and J. Wong 1981: "Comparison of Modeled and Measured Deposition for the Withlacoochee Spray Trials," U. S. Department of Agriculture Forest Service Forest Pest Management Methods Applications Group Report No. 81-3.

5. J. E. Rafferty and J. F. Bowers 1989: "Comparison of FSCBG2 and FSCBG3 Aerial Spray Model Predictions with Field Measurements," USDA Forest Service Forest Pest Management and U. S. Army Test and Evaluation Command Aberdeen Proving Ground, Report Number DPG-FR-90-001.

6. R. E. Sandquist 1989: "A Study Plan for a Preliminary Efficacy Evaluation of a Recommended Aerial Spray Regime to Suppress Douglas-fir Cone and Seed Insects (A Sub-Study of a Demonstration of the Feasibility of using Helicopters to Apply Insecticides to Douglas-fir Seed Orchards)," USDA Forest Service Pacific Northwest Region Forest Pest Management.

7. K. P. Bentson 1989: "A Study Plan for Canopy Deposition and Penetration of Azinphos-methyl (Guthion) and S-fenvalerate (Pydrin) in a Seed Orchard Aerial Application," USDA Forest Service Pacific Northwest Research Station.

8. R. E. Sandquist 1990: "Efficacy Evaluation of a Recommended Aerial Spray Regime to Suppress Douglas-fir Cone and Seed Insects (A Sub-Study of a Demonstration of the Feasibility of using Helicopters to Apply Insecticides to Douglas-fir Seed Orchards)," USDA Forest Service Pacific Northwest Region Forest Pest Management, Report Number R6-90-1.

9. K. P. Bentson 1989: "Heather Seed Orchard -- Spray Deposition on Cards and Foliage," USDA Forest Service Pacific Northwest Research Station.

10. K. P. Bentson, R. E. Sandquist, B. Hawley and J. W. Barry 1990: "Insecticide Spray Deposition in a Douglas-fir Seed Orchard from Aerial Applications," USDA Forest Service Pacific Northwest Research Station.

11. M. E. Teske 1989: "Work Plan for the Heather Seed Orchard Deposition Study in Support of FSCBG Modeling Comparisons," Continuum Dynamics, Inc. Technical Note No. 89-07.

12. M. E. Teske 1989: "Test Matrix Calculations for the Heather Seed Orchard Deposition Study in Support of FSCBG Modeling Comparisons," Continuum Dynamics, Inc. Technical Note No. 89-09.

13. C. E. Hardy 1987: "Aerial Application Equipment," U. S. Department of Agriculture Forest Service Equipment Development Center Report No. 8734-2804.

14. W. E. Yates, N. B. Akesson and R. E. Cowden 1984: "Measurement of Drop Size Frequency from Nozzles Used for Aerial Applications of Pesticides in Forests," U. S. Department of Agriculture Forest Service Equipment Development Center Report No. 8434-2804.

15. R. B. Ekblad, K. Windell and B. Thompson 1990: "EMCOT Weather Station," USDA Forest Service Technology and Development Program Report No. 9034-2806-MTDC.

16. S. R. Hanna 1989: "Confidence Limits for Air Quality Model Evaluations, as Estimated by Bootstrap and Jackknife Resampling Methods," Atmospheric Environment, Volume 23, Pages 1385-1398.

APPENDIX

Included in this Appendix are the meteorological data records for the June and July spray applications (Figures A-1 and A-2 respectively) and the pretest predictions by FSCBG for the June and July spray applications (Figures A-3 to A-6).

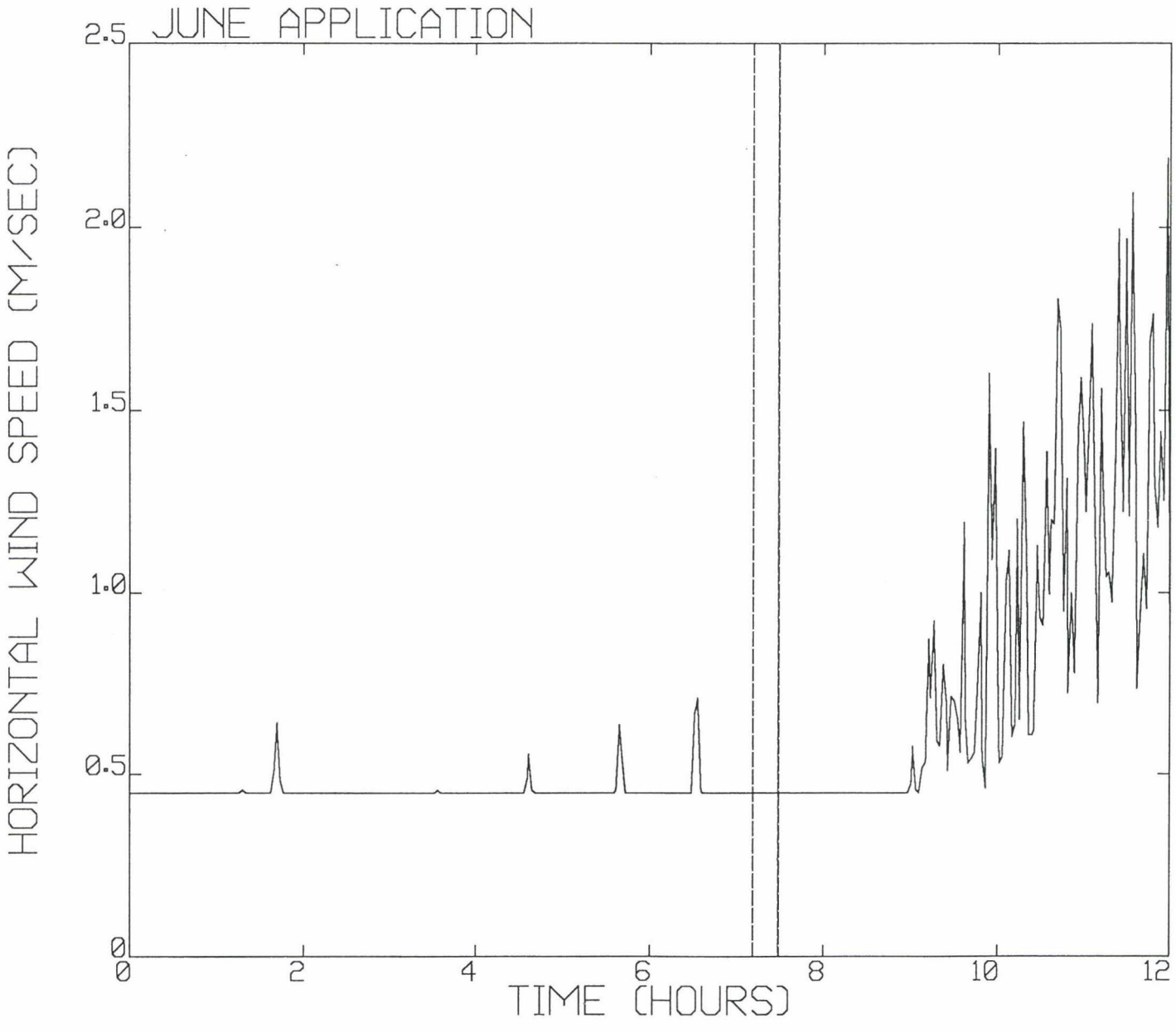

Figure A-1: Meteorological conditions recorded during the first twelve hours of June 7, 1989, at Heather Seed Orchard (test time: 7.20 hours to 7.50 hours) as indicated by the vertical lines. (A) Horizontal wind speed.

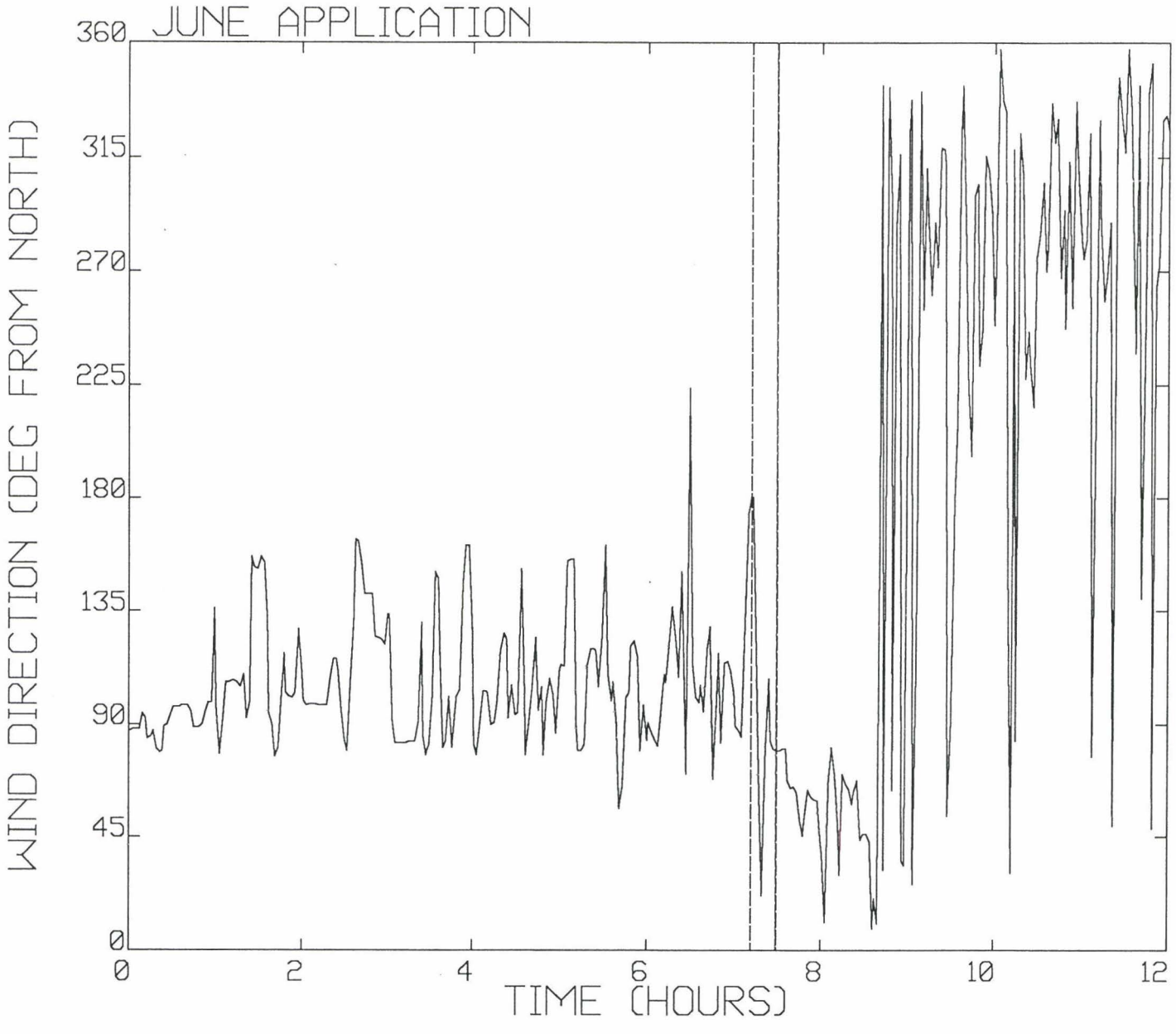

Figure A-1 (Continued): Meteorological conditions recorded during the first twelve hours of June 7, 1989, at Heather Seed Orchard (test time: 7.20 hours to 7.50 hours) as indicated by the vertical lines. (B) Horizontal wind direction.

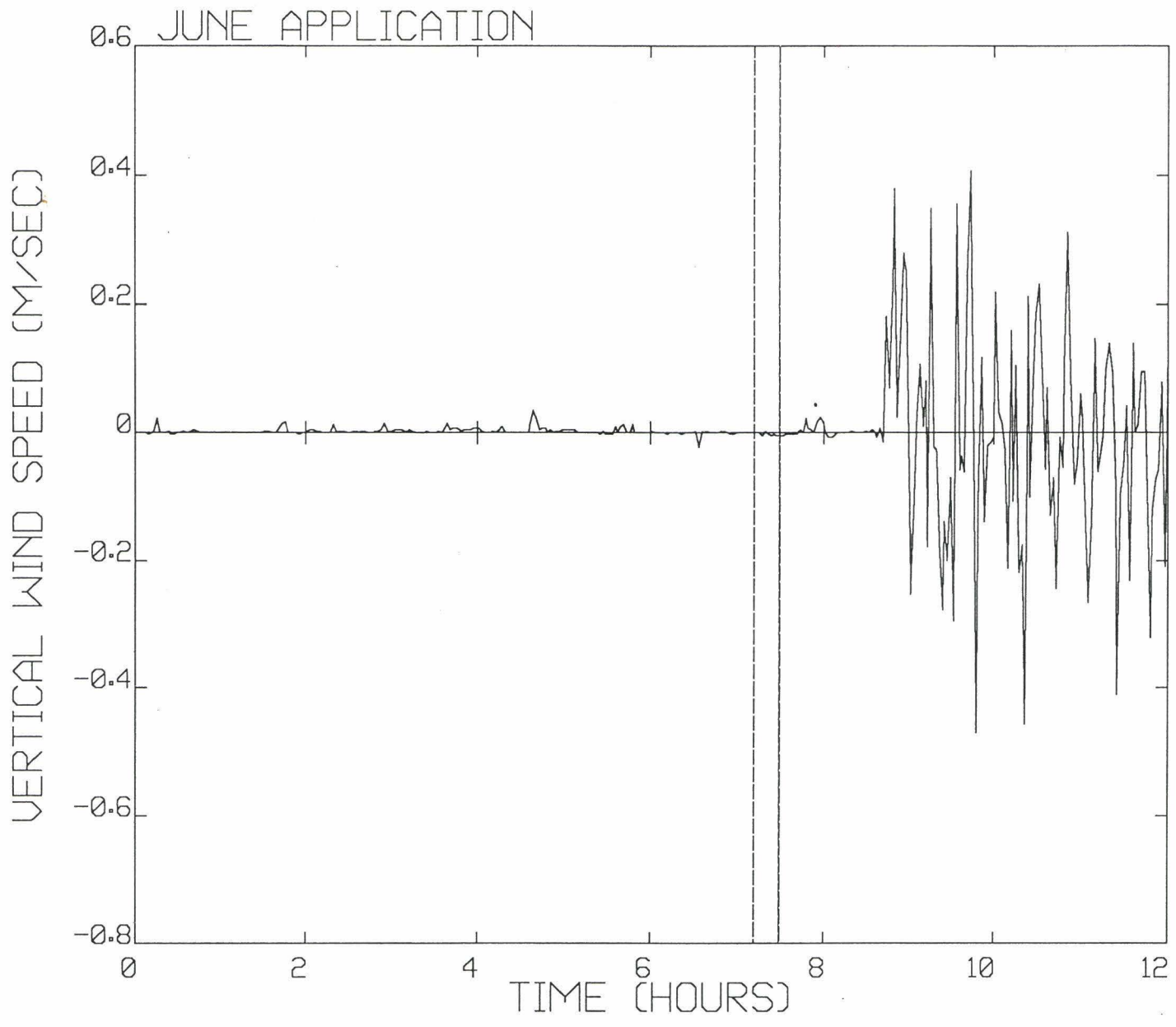

Figure A-1 (Continued): Meteorological conditions recorded during the first twelve hours of June 7, 1989, at Heather Seed Orchard (test time: 7.20 hours to 7.50 hours) as indicated by the vertical lines. (C) Vertical wind speed.

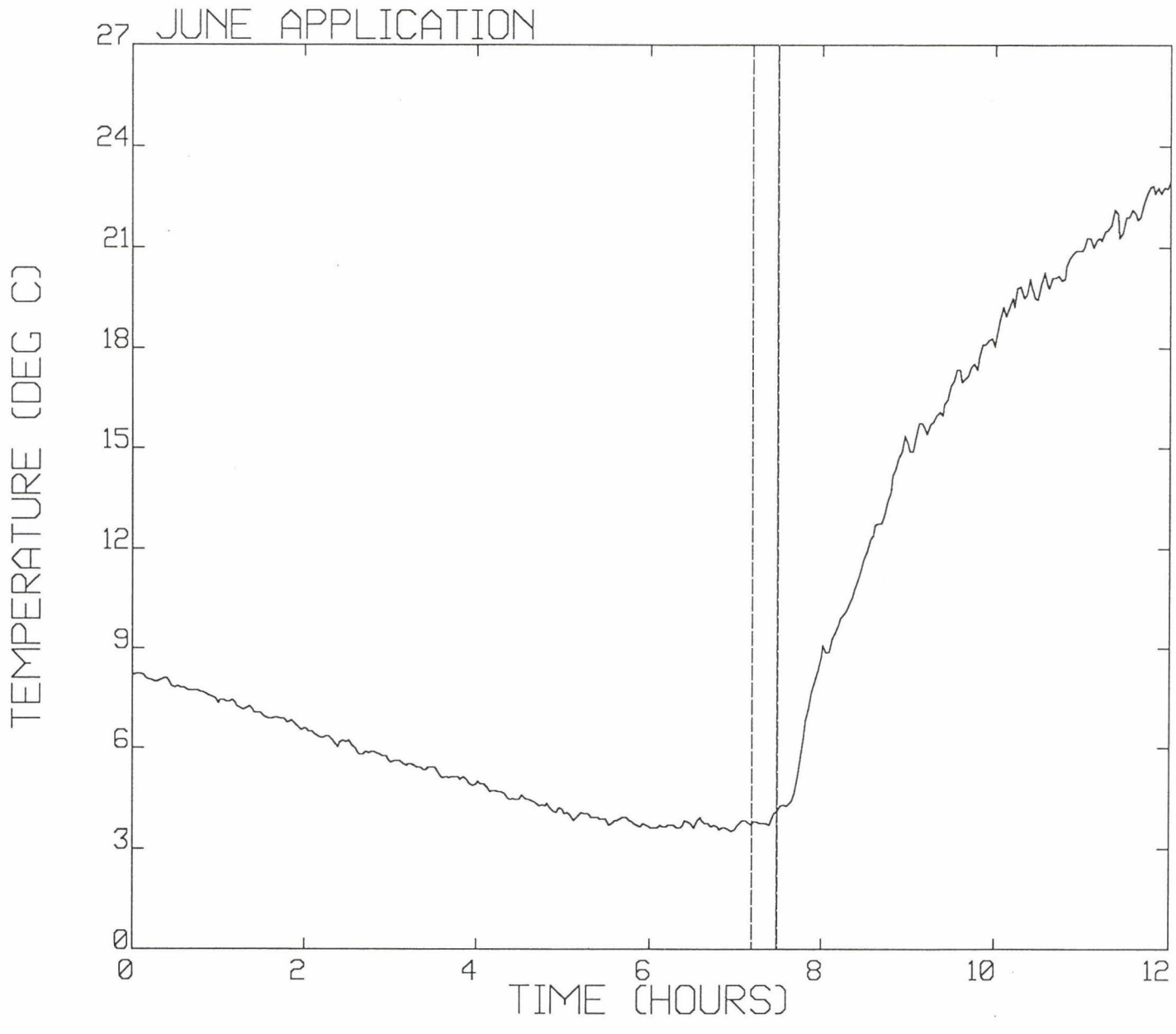

Figure A-1 (Continued): Meteorological conditions recorded during the first twelve hours of June 7, 1989, at Heather Seed Orchard (test time: 7.20 hours to 7.50 hours) as indicated by the vertical lines. (D) Ambient temperature.

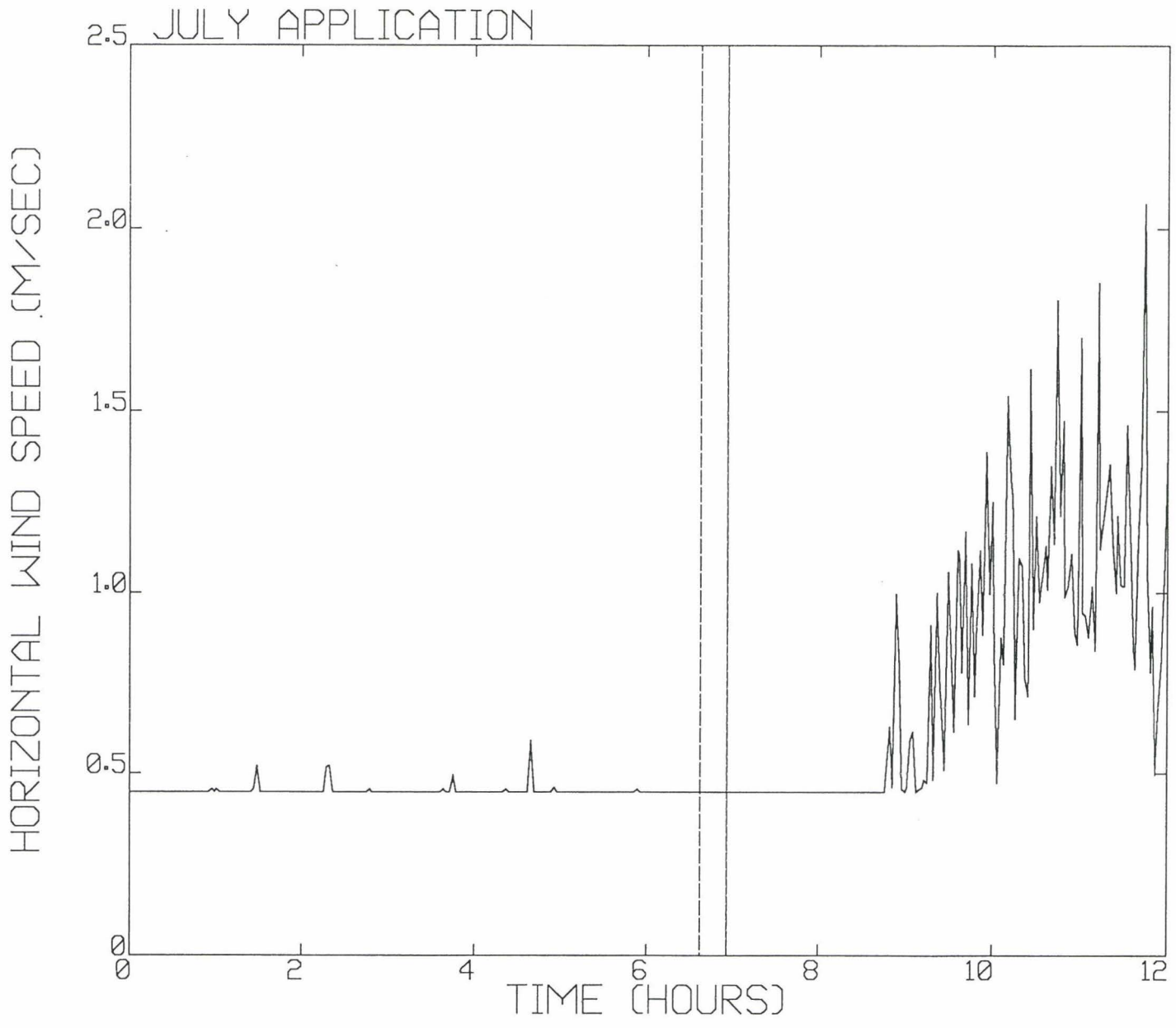

Figure A-2: Meteorological conditions recorded during the first twelve hours of July 6, 1989, at Heather Seed Orchard (test time: 6.65 hours to 6.95 hours) as indicated by the vertical lines. (A) Horizontal wind speed.

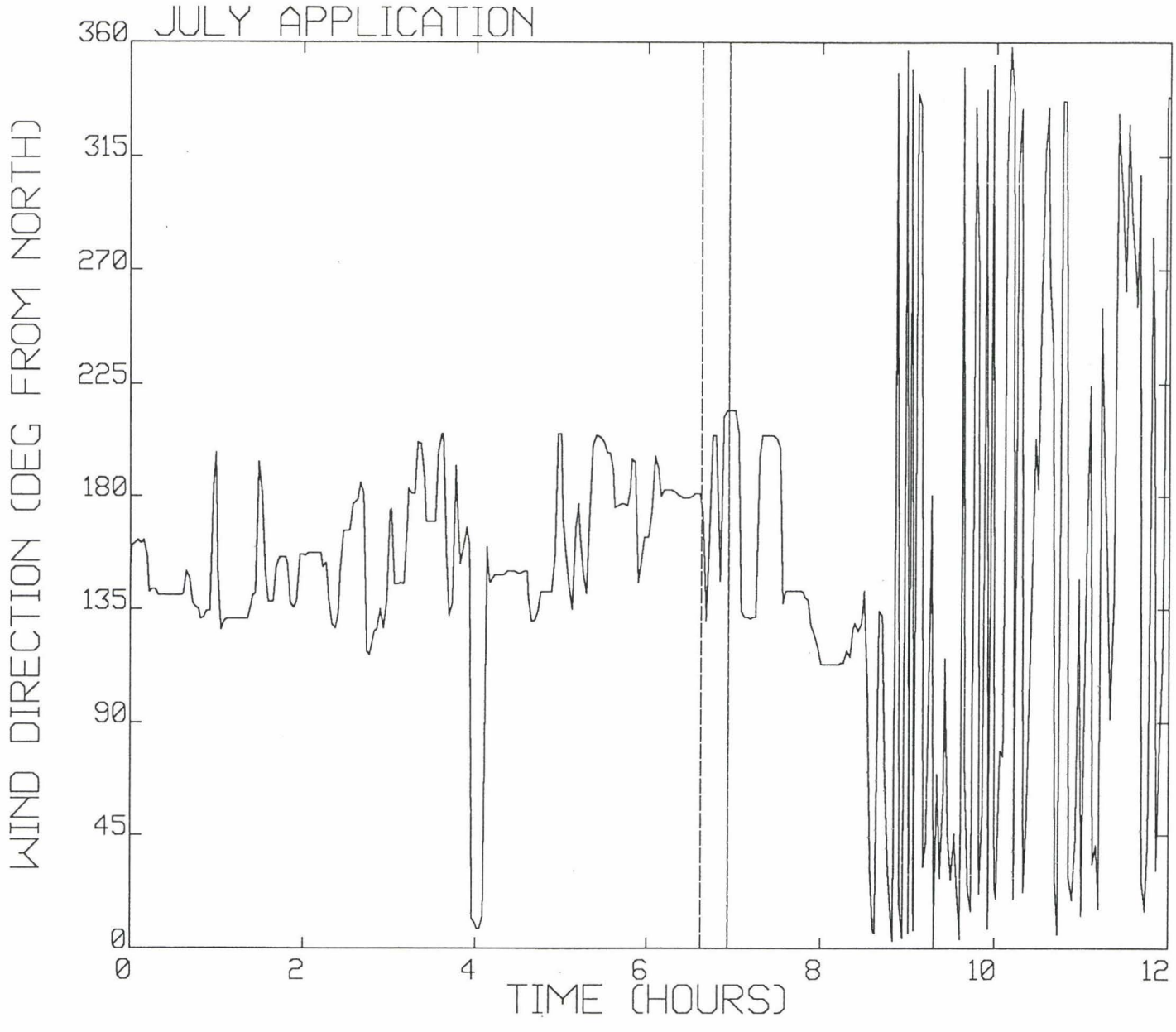

Figure A-2 (Continued): Meteorological conditions recorded during the first twelve hours of July 6, 1989, at Heather Seed Orchard (test time: 6.65 hours to 6.95 hours) as indicated by the vertical lines. (B) Horizontal wind direction.

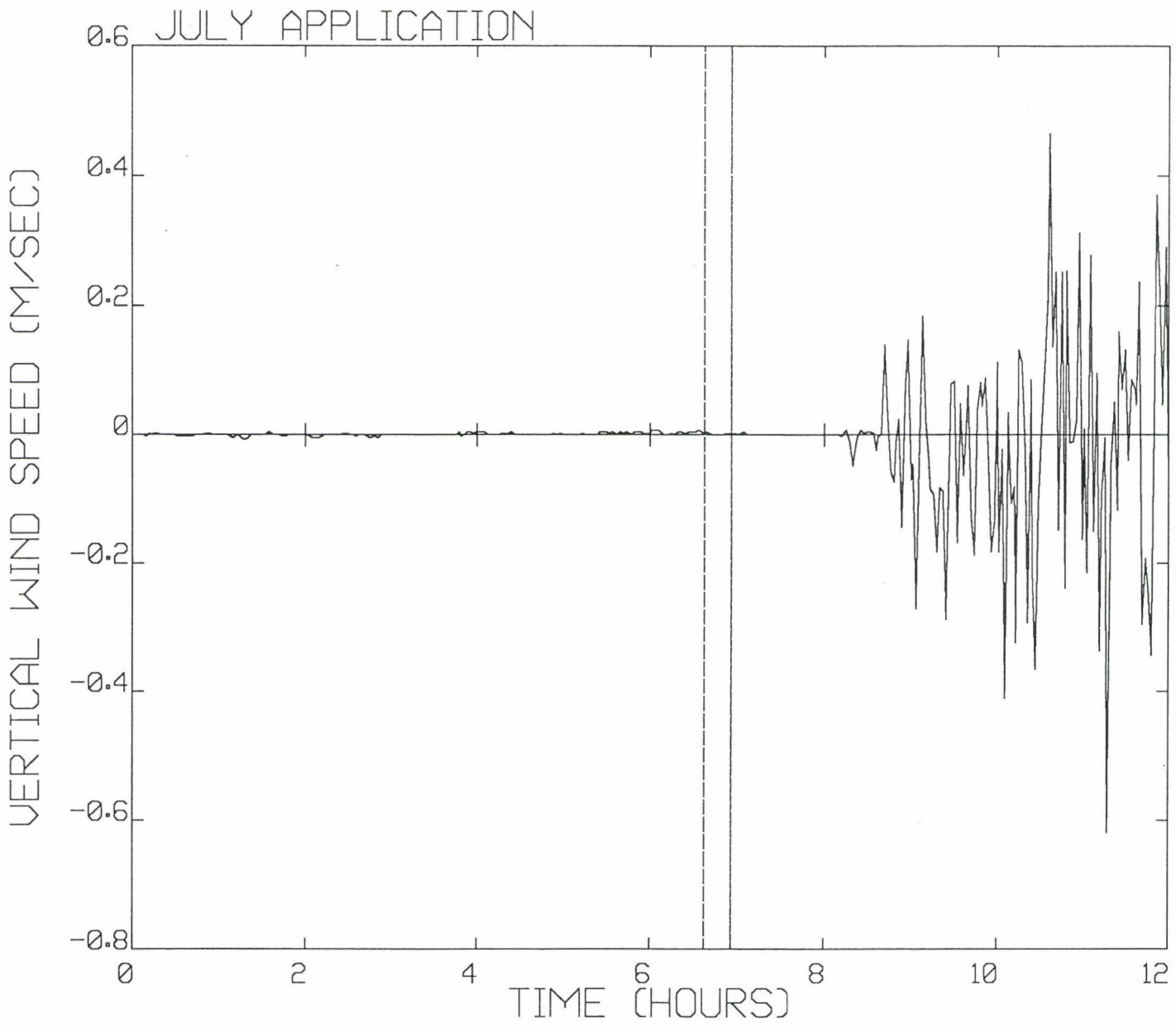

Figure A-2 (Continued): Meteorological conditions recorded during the first twelve hours of July 6, 1989, at Heather Seed Orchard (test time: 6.65 hours to 6.95 hours) as indicated by the vertical lines. (C) Vertical wind speed.

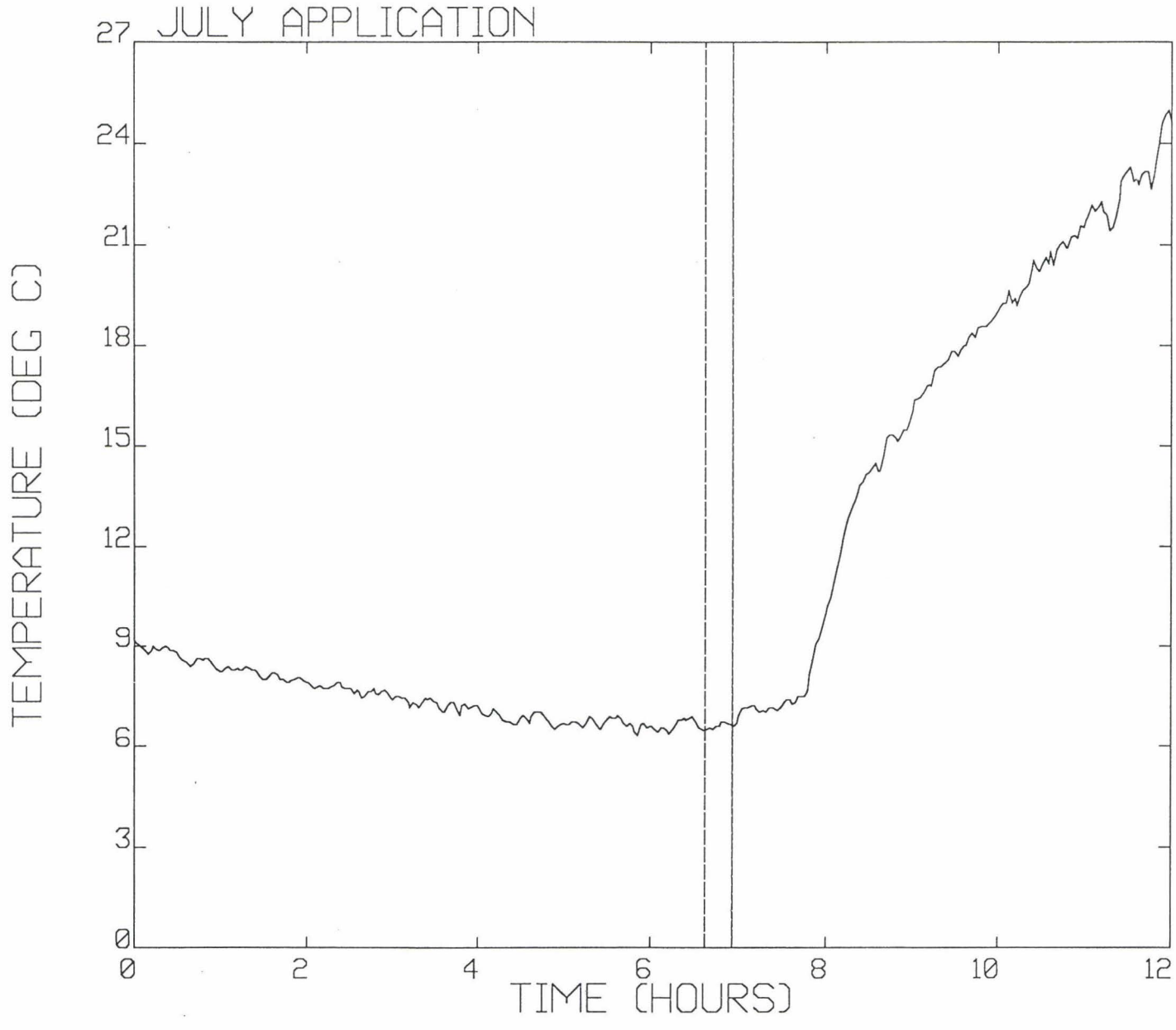

Figure A-2 (Continued): Meteorological conditions recorded during the first twelve hours of July 6, 1989, at Heather Seed Orchard (test time: 6.65 hours to 6.95 hours) as indicated by the vertical lines. (D) Ambient temperature.

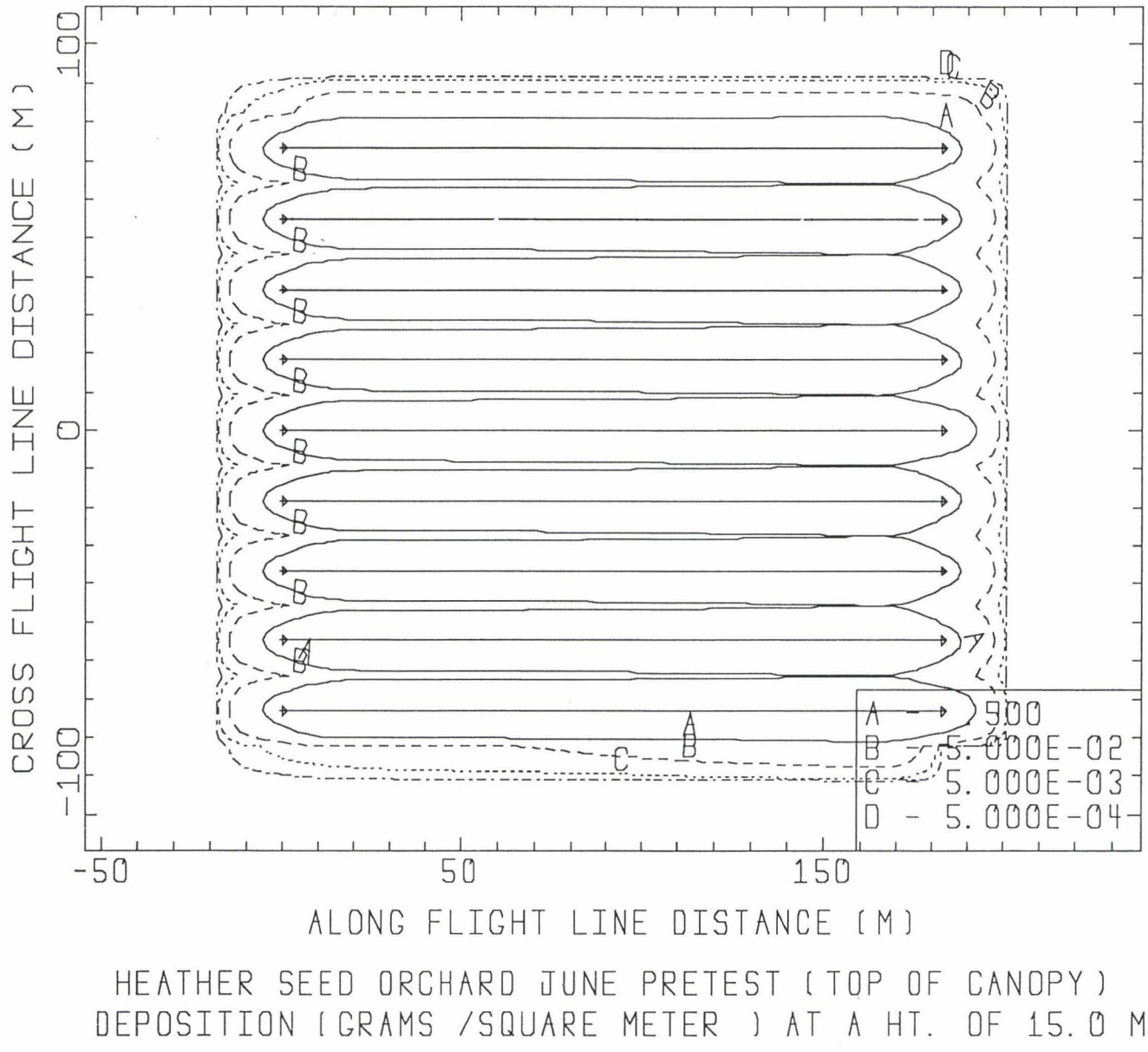

Figure A-3: Deposition contours at the top of the Heather Seed Orchard canopy for the anticipated June application. Maximum predicted deposition is 4.64 gm/m^2. Contour levels of 0.5, 0.05, 0.005 and 0.0005 gm/m^2 are indicated.

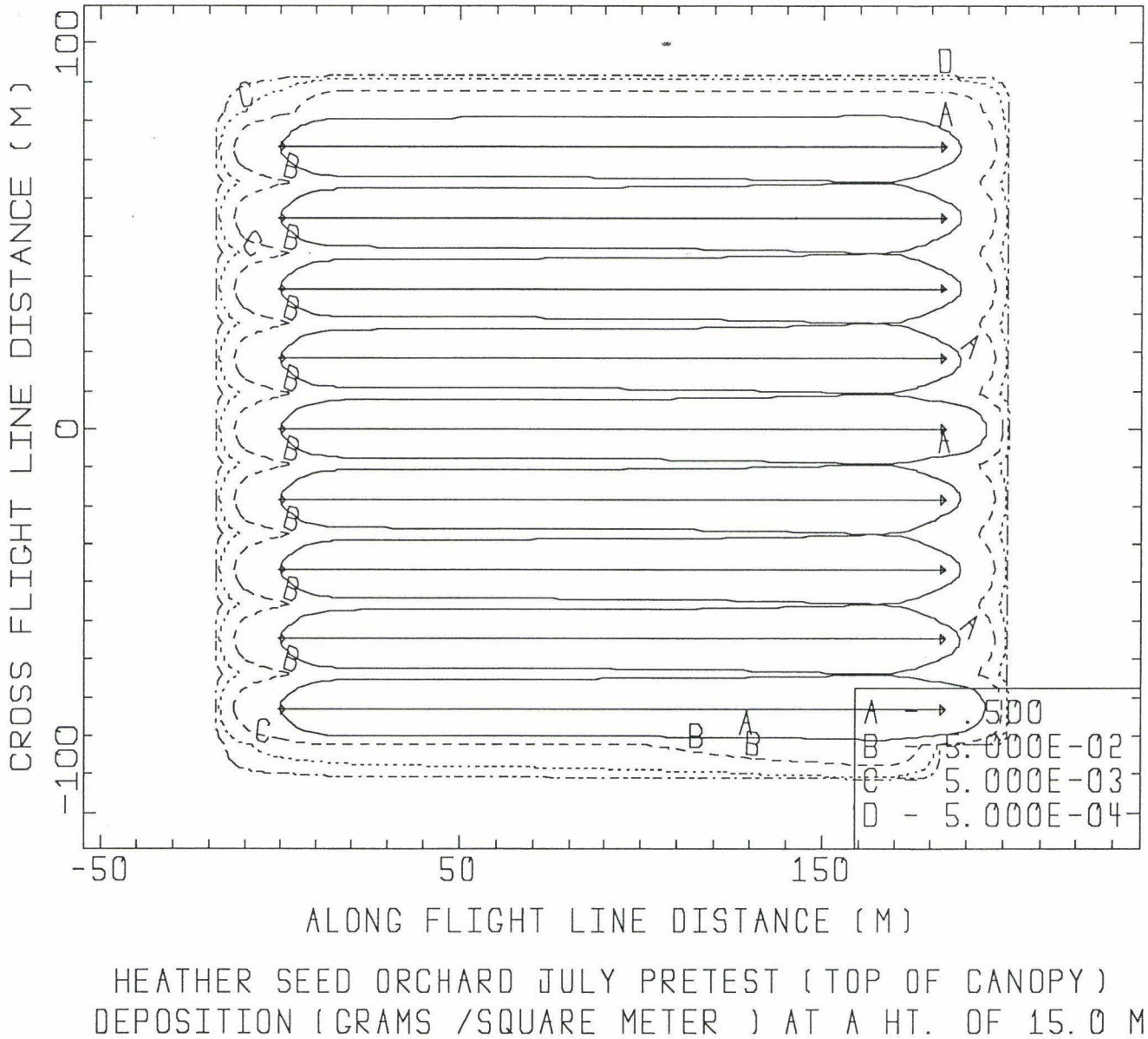

Figure A-4: Deposition contours at the top of the Heather Seed Orchard canopy for the anticipated July application. Maximum predicted deposition is 4.44 gm/m^2. Contour levels of 0.5, 0.05, 0.005 and 0.0005 gm/m^2 are indicated.

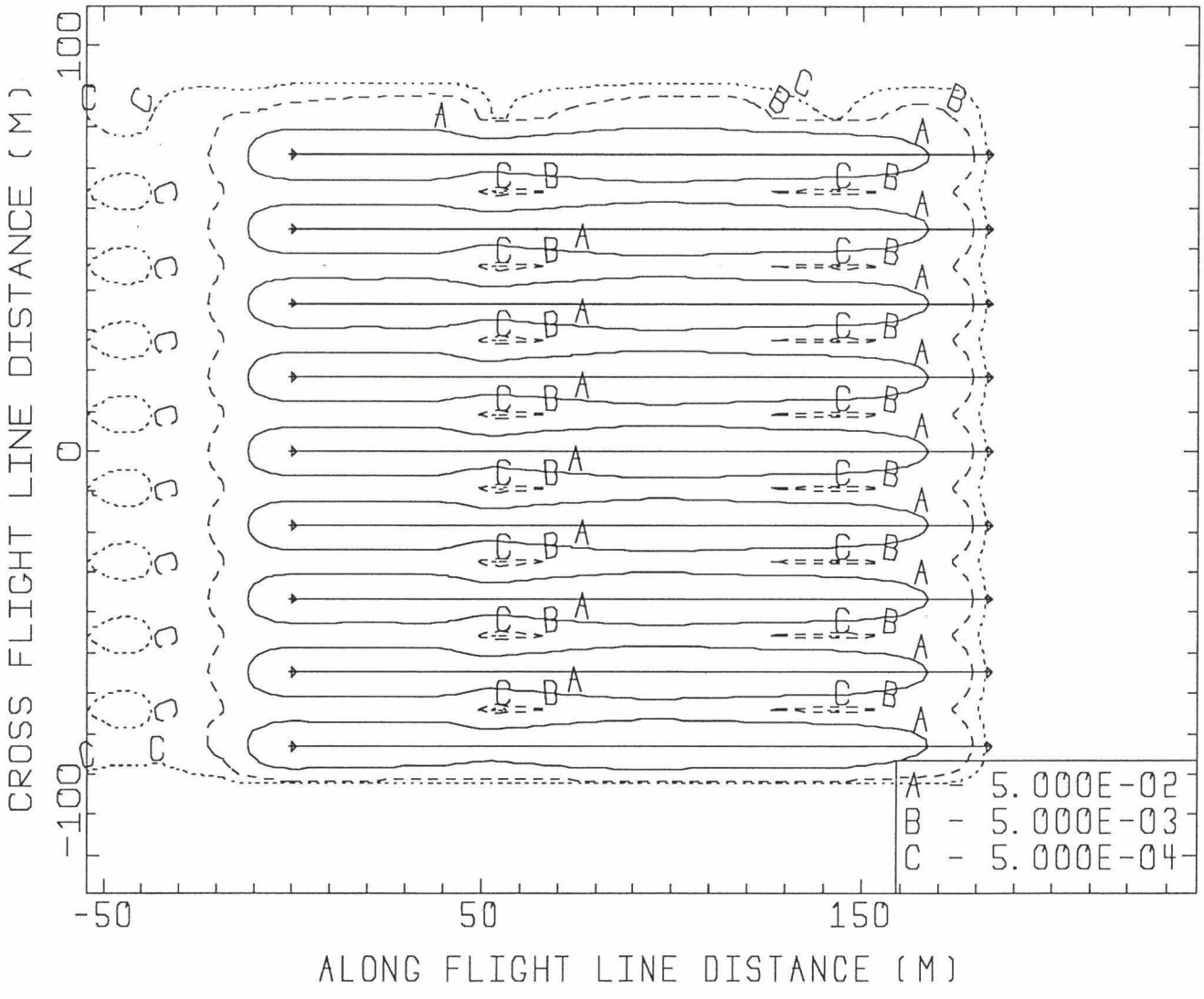

Figure A-5: Deposition contours at the ground of the sparse tree stand area in the Heather Seed Orchard canopy for the anticipated June application. Maximum predicted deposition is 0.167 gm/m^2. Contour levels of 0.05, 0.005 and 0.0005 gm/m^2 are indicated.

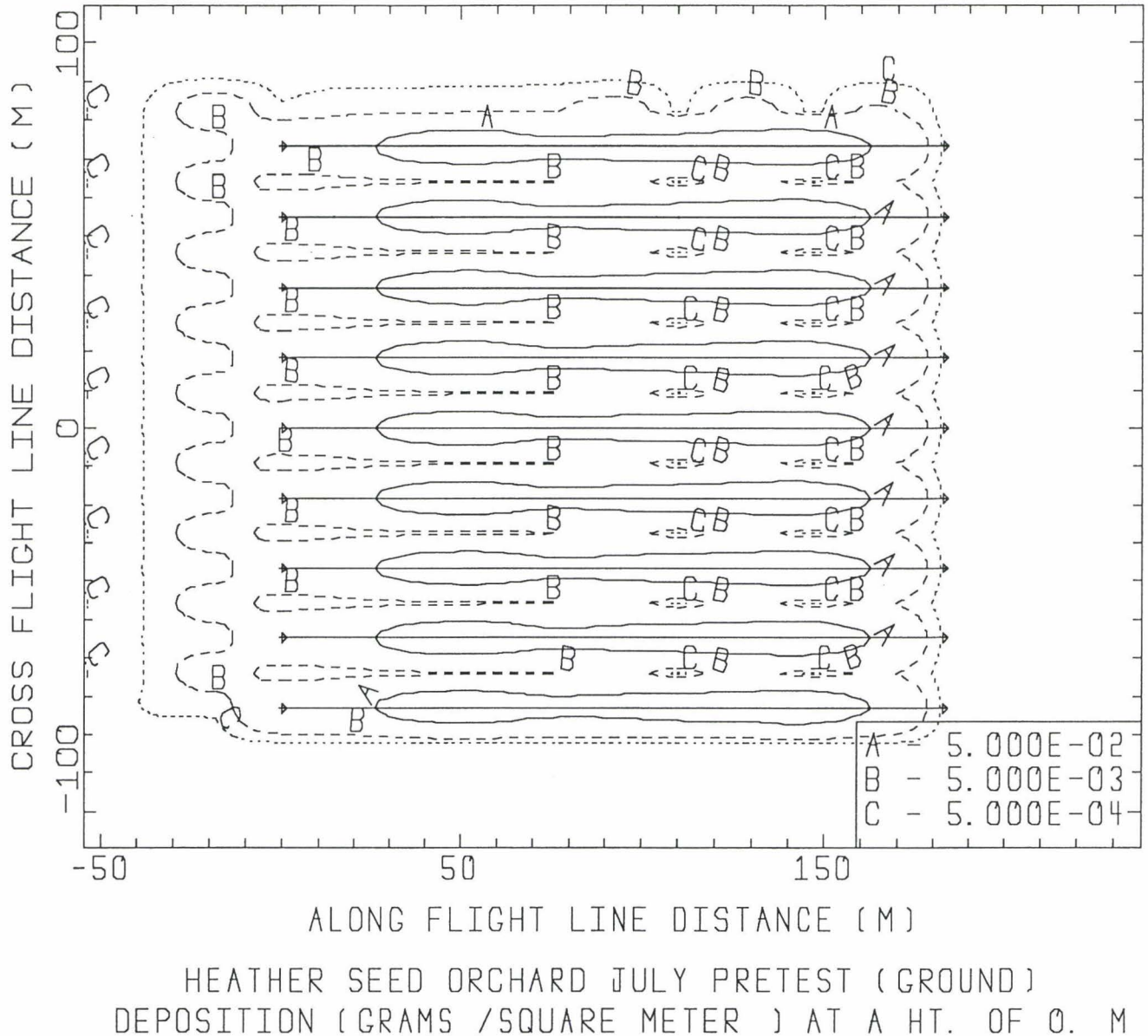

Figure A-6: Deposition contours at the ground of the sparse tree stand area in the Heather Seed Orchard canopy for the anticipated July application. Maximum predicted deposition is 0.093 gm/m^2. Contour levels of 0.05, 0.005 and 0.0005 gm/m^2 are indicated.